Economic and Environmental Benefits and Costs of Conservation Tillage

Economic Research Service
U.S. Department of Agriculture

In collaboration with the
Natural Resources Conservation Service
U.S. Department of Agriculture

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The Economic and Environmental Benefits and Costs of Conservation Tillage. U.S. Department of Agriculture, Economic Research Service in collaboration with the Natural Resources Conservation Service.

Abstract

Conservation tillage is an important conservation practice that can significantly reduce soil erosion. Use of conservation tillage produces significant benefits to farmers and the Nation by reducing soil erosion and mitigating potentially adverse off-site impacts on water quality and wildlife habitat. Gains from further adoption on highly erodible land are estimated to be modest—a testament to the success of the switch to conservation tillage so far. Looking to the future, questions remain about the valuation of benefits associated with soil quality, wildlife habitat, and carbon sequestration. Moreover, continued use or expansion of conservation tillage may be very sensitive to changes in Federal program provisions, especially those related to compliance-type mechanisms.

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Executive Summary

In their reports on the FY 1997 *Agriculture, Rural Development, Food and Drug Administration, and Related Agencies Appropriations Bill* (House Report 104-613, Senate Report 104-317), both the House and Senate Appropriations Committees requested that ERS, in cooperation with NRCS, do a comprehensive study of conservation tillage. Specifically:

> The Committee directs the Economic Research Service, in cooperation with the Natural Resources Conservation Service, to do a comprehensive study of conservation tillage. The study should include the current status of conservation tillage and the benefits to agriculture, the environment, and society as a whole, as well as recommendations concerning what actions are needed to increase the use of conservation tillage and estimates of the benefits and costs of doing so.

This report is in fulfillment of that request.

Soil erosion from U.S. cropland has long been recognized as a national problem. Concern initially focused on the loss of fertile topsoil and fear that agricultural productivity would decline. More recently, there has been a growing understanding of how soil erosion can impair water quality, as sediment—often mixed with agricultural chemicals—enters rivers, lakes, and streams. Conservation tillage is an important conservation practice that can significantly reduce soil erosion. Use of conservation tillage produces significant benefits to farmers and the Nation by reducing soil erosion and mitigating potentially adverse off-site impacts on water quality and wildlife habitat. Gains from further adoption on highly erodible land are estimated to be modest—a testament to the success of the switch to conservation tillage so far. Looking to the future, questions remain about the valuation of benefits associated with soil quality, wildlife habitat, and carbon sequestration. Moreover, continued use or expansion of conservation tillage may be very sensitive to changes in Federal program provisions, especially those related to compliance-type mechanisms.

Conservation tillage is a tillage system that leaves enough crop residue on the field after harvest to protect the soil from erosion. Types of conservation tillage include mulch tillage, ridge tillage, and no-tillage. In addition to reducing soil erosion and improving water quality, other benefits of conservation tillage include improving quality of agricultural soil by increasing organic matter, sequestering carbon, and providing habitat and food for wildlife.

The use of conservation tillage increased from 2 percent of planted acreage in 1968 to nearly 36 percent of planted acreage in 1996. Conservation tillage is most commonly used on soybeans, corn, and small grains. More than 40 percent of total corn and soybean planted acreage in 1996 was conservation tilled. Where double-cropping was used, nearly 70 percent of soybean acreage, 46 percent of corn acreage, and 37 percent of sorghum acreage employed conservation tillage systems. Other important crops, like peanuts, potatoes, beets, tobacco, and vegetables, have also improved residue management and erosion control, even though their cultural practices preclude the use of conservation tillage.

The adoption of conservation tillage varies widely across States and regions. In 1996, Kentucky led the Nation in conservation tillage, with an adoption rate of 73 percent; Delaware, Iowa, Maryland, Missouri, Nebraska, and Tennessee all had between 50 and 63 percent of cropland conservation-tilled. Arizona, Florida, Massachusetts, Rhode Island, and

Vermont had adoption rates of less than 10 percent. The Appalachian and Corn Belt regions led in conservation tillage adoption with 48 and 46 percent, respectively, while the Delta, Southeast, Pacific, and Southern Plains had only between 18 and 23 percent.

While the adoption of conservation tillage has generally exhibited a steady upward trend, acres under conservation tillage can be highly variable year to year, due to unforeseen external factors such as weather and pest infestations. For example, the substantial decrease in the use of conservation tillage in some Midwestern States between 1993 and 1994 reflects the heavy rains and flooding in 1993 that destroyed crop acreage. Nearly 5 million fewer acres were planted in 1993 than in 1992 and 1994. Most of this land was returned to production in 1994, but rills and gullies on the surface and sand and soil deposits on the bottomlands forced farmers to till the soil more. The use of conservation tillage in Illinois decreased 16.3 percent between 1993 and 1994 while Kansas, Minnesota, Ohio, and Wisconsin experienced similar, although less precipitous, declines.

Mulch tillage is the dominant type of conservation tillage although there is increased use of no-tillage. Mulch tillage accounted for 57 percent of conservation tillage and was used on 20 percent of the Nation's cropland in 1996. No-tillage, used on 15 percent of the Nation's cropland, accounted for 41 percent of conservation tillage, while ridge tillage was used on only about 1 percent of the cropland in 1996. Over the past few years, there has been little change in the use of no-tillage relative to mulch tillage.

Conservation tillage is used about 8 to 10 percent more extensively on highly erodible land (HEL) than on non-highly erodible land (NONHEL). In 1969, 103.8 million acres were under conservation tillage. When total planted acreage for major field crops is considered, about 28 percent of conservation tillage occurs on HEL. For corn and soybeans, the growth in the use of conservation tillage has been greater on HEL than on NONHEL, while for wheat there has been little aggregate change since 1989.

The use of conservation tillage on an additional 48 million acres of HEL and 166 million acres of non-highly erodible cropland would yield a total reduction in erosion of 326 million tons per year. Additionally, the annual benefits of converting the remaining 22.4 million acres of HEL on which no conservation system is currently used to conservation tillage are relatively modest—approximately $50 million. Improvements in wildlife habitat and possible carbon sequestration would yield additional benefits, which are difficult to quantify with precision.

Yield benefits associated with the continuous use of conservation tillage take a relatively long time to materialize. Crops for which data are available (corn, soybeans, and wheat—winter, spring, and durum) show no statistically identifiable association between tillage practice and yield for the years 1990 to 1995: yields are neither higher nor lower. There is, however, greater variability in yield for winter wheat, spring wheat, and durum wheat that are conservation tilled.

Recent USDA data indicate that, with one or two exceptions, fertilizer use on conservation tilled acreage was not statistically significantly different than fertilizer use on conventional tilled acreage for 1990-1994. The results of field experiments indicate that an increase in the amount of crop residue cover on the soil surface tends to keep soils cooler, wetter, less aerated, and denser. These characteristics and the resulting beneficial impacts from increased organic matter, improved moisture retention and permeability, and reduced

nutrient losses from erosion can affect the ability of crops to utilize nutrients. With higher levels of crop residue, proper timing and placement of nutrient applications are critical to enhance fertilizer efficiency to achieve optimal yield at lowest cost. Additionally, the number of trips across a field to apply fertilizer did not vary between tillage systems. Consequently, there are no statistically significantly differences in labor costs or machinery operating and maintenance expenses associated with the application of fertilizer between conservation tillage and conventional tillage.

Few definitive statements can be made about pesticide use under conservation tillage versus conventional tillage. More herbicides are typically used during the first few years of conservation tillage. Insecticide use falls with conservation tillage. The existing cropping pattern, however, plays an important role in determining pesticide requirements because monoculture systems generally require greater pesticide use than crop rotation systems.

Lower fuel and maintenance costs associated with conservation tillage may be overshadowed by the higher cost of new conservation tillage implements. If conservation tillage, which may require fewer implements and field operations, is used on only part of the cropland, implements and tractors will need to be available for other conventionally tilled acres. For example, using a drill or narrow-row planter for soybeans is an option for most tillage systems but owning a drill for soybeans and a planter for corn often increases the machinery inventory and costs for a corn-soybean farm. Additionally, a farmer who decides to convert from conventional tillage to conservation tillage exclusively must consider how to value his or her existing conventional tillage equipment. This equipment might not be fully depreciated and farmers often have limited alternatives on how it might otherwise be used.

Conservation tillage reduced sheet and rill erosion by about 66 million tons in 1996. The best estimate of annual social benefits associated with this reduction is about $103 million. Conservation tillage reduced wind erosion by about 31.5 million tons in 1996, providing a social benefit of about $45 million.

The decision to adopt conservation tillage is based on several interrelated factors such as crop grown, the cost of the tillage systems (variable costs and capital costs), weather and pest expectations, and management experience. Farmers will adopt conservation tillage if they perceive a gain in net benefits from switching technologies. Beyond the direct monetary factors reflected on a business balance sheet, farmers may consider nonmonetary adjustment costs such as having to learn new skills or deal with new suppliers when they assess whether to change production practices. Farmers' private decisions do not typically include the benefits or costs to society associated with the use of a new practice.

USDA policies play an important role in the adoption of conservation tillage. Soil conservation policies have existed in the United States for more than 60 years. Initially, these policies focused on the on-farm benefits of keeping soil on the land and increasing net farm income. Beginning in the 1980's, however, policy goals increasingly included reductions in off-site impacts of erosion. Conservation tillage was included in the suite of best management practices (BMP's) recommended within most conservation programs. The Food Security Act of 1985 was the first major legislation explicitly to tie eligibility for agricultural program payments to conservation performance. The adoption of conservation tillage on highly erodible land increased significantly as the conservation compliance provisions of the 1985 Food Security Act took effect. The Federal Agriculture Improvement and Reform Act (FAIR) of 1996 modifies the conservation compliance provisions by providing farmers with greater

flexibility in developing and implementing conservation plans. Noncompliance for those on HEL can result in loss of eligibility for many payments, such as production flexibility contract payments. While conservation compliance has been an effective tool in motivating the adoption of conservation tillage on HEL, many farmers have adopted conservation tillage solely because it is profitable to do so.

Financial incentives may be necessary to induce the voluntary adoption of conservation tillage by farmers for whom the practice would not be more profitable than conventional tillage but on whose land the use of conservation tillage would provide substantial offsite benefits. Public education and technical assistance policies to promote the use of conservation tillage have been very effective. University and private sources of information assistance also influence farmers' technology choices when the conservation tillage practices are profitable. When the adoption of conservation tillage will provide significant public benefits but will not be more profitable for the farmer, financial incentives may change farmers' practices.

The Economic and Environmental Benefits and Costs of Conservation Tillage

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I. Introduction

Soil erosion from cropland in the United States has been recognized as an important problem for over 60 years. Concern initially centered on the loss of fertile topsoil and fear that agricultural productivity would decline. More recently, however, there has evolved a growing understanding of the off-farm impacts of sediment and chemical transport (Environmental Protection Agency, 1994). Reducing erosion on the Nation's agricultural lands, therefore, offers both private (onfarm) and public (off-farm) benefits.

Conservation tillage is one of many conservation practices developed to reduce soil erosion. In its broadest sense, conservation tillage is as a tillage system that leaves enough crop residue on the field after harvest to protect the soil from erosion. In general, tillage that leaves a residue cover of at least 30 percent after planting is deemed conservation tillage; residue cover will vary, however, according to soil type, slope, crop rotation, winter crop cover, and other factors.

Conservation tillage has benefits beyond keeping soil on the field. After several years under the practice, the soil's organic matter and structure may improve, thus increasing the quality of the soil. The change in organic content and the lack of soil disturbance also serve to sequester carbon, which may have long-term environmental benefits. Cropland on which conservation tillage is used also can serve as habitat for wildlife. The residue left on the field offers food for some species and shelter for others.

It is important to recognize that conservation tillage, while having a fairly precise definition, consists of several different tillage practices, including mulch tillage, ridge tillage, and no-tillage. (These different tillage practices are defined in table 2.1 in the next chapter). These subcategories of conservation tillage can exhibit different economic and environmental benefits and costs. For example, the generally higher crop residue cover associated with no-tillage results in a lower rate of soil erosion than other conservation tillage practices such as mulch or ridge tillage. No-tillage also results in greater water quality benefits, greater wildlife benefits, and lower equipment requirements, and has the greatest potential impact on improving soil quality, since soil is not disturbed except for a small area where the seed is placed during planting (Zero Tillage Farmers Association, 1997).

Conservation tillage is not used on most U.S. cropland. In 1996, conservation tillage was used on 103.8 million acres of the total 290.2 acres planted. The decision to change production technologies is based on many factors. Farmers will adopt conservation tillage if they perceive a gain in net benefits from switching technologies. The net benefits can represent more than just the direct monetary factors reflected on a business balance sheet. Farmers also include nonmonetary adjustment costs such as having to learn new skills or deal with new suppliers when they assess whether to change production practices. What is not typically included in farmers' private decisions are the benefits or costs to society associated with the use of a new practice. The purpose of this study is to identify, and quantify to the extent possible, the likely benefits and costs associated with the use of conservation tillage to farmers and the public.

The current status of conservation tillage adoption is described in Chapter 2. Use of the technology varies widely by crop and by region, and factors affecting the adoption decision are discussed.

In Chapter 3, the onfarm and off-farm benefits and costs of conservation tillage adoption are identified. Conservation tillage and conventional tillage are compared with respect to yields and costs of production. Differences in input use are also described. As with many resource-conserving technologies, the relative advantage of conservation tillage depends on farm and regional characteristics (Caswell et al., 1993). The offsite or off-farm impacts of soil erosion, particularly with respect to water quality, are identified, and the benefits of tillage adoption on wildlife habitat and the reduction of carbon emissions are described.

This study analyzes the reduction of soil erosion that would result from the adoption of conservation tillage on lands for which the technology is considered suitable. Using figures developed by Ribaudo (1989) and Huszar and Piper (1986), estimates are made of the public benefits that would be realized from the adoption-induced reductions in offsite erosion impacts. The results of this analysis are described in Chapter 3.

If the offsite and onsite benefits of increasing the use of conservation tillage are greater than the costs to farmers of adopting the technology, public policies can influence farmers to adopt conservation tillage. A lexicon of these policy options is provided in Chapter 4. The U.S. Government, primarily through the U.S. Department of Agriculture, has developed a suite of policies to promote the use of preferred agricultural practices. These policies and their effect on the adoption of conservation tillage are also described.

Conservation Tillage in Historical Context

The use of crop residue in the United States to sustain soil productivity dates to the early 18th century. Colonists from Europe, observing the more severe storms in the New World than those encountered in the Old, realized the need to use cover crops and crop residue to mitigate soil erosion (Moldenhauer et al., 1994). Throughout the 19th century, farmers experimented with alternative production practices to produce food and fiber without degrading soil resources. It was only in the 1920's, however, that field experiments were initiated to assess objectively the effects of sheet and rill erosion[1] and wind erosion on soil productivity. These early efforts were disparate and tended to focus on issues of concern to a specific geographic

[1] Sheet and rill erosion is the most common form of agricultural soil erosion, occurring when raindrops or irrigation detach soil particles from the soil surface and transport them in thin sheets of water moving across unprotected slopes. As runoff water becomes concentrated first into rills and then into separate channels, it begins to cut gullies, removing larger volumes of soil.

area, for example, corn in Illinois (Odell et al., 1984). Unfortunately, there are no objective measures available on how these efforts affected farmer behavior and net farm income (private benefits) or the extent to which soil erosion was reduced (public benefits) and soil productivity enhanced.

With the establishment of the Soil Conservation Service of the U.S. Department of Agriculture in 1935, now known as the Natural Resources Conservation Service, a more organized and comprehensive assessment of conservation tillage began. A large number of conservation tillage practices such as mulch tillage were evaluated at land-grant university experiment stations throughout the United States (Moldenhauer et al., 1994). The evaluations quickly revealed that due to spatial variation in soil characteristics and weather patterns, farming with conservation tillage requires a different approach to soil preparation, fertilizer application, and weed and insect control, and an awareness of the topography of the land farmed in relation to water sources. Therefore, conservation tillage technology was difficult to transfer unilaterally across major soil resource areas. Thus, conservation tillage diversity would be the norm, and conservation tillage practices would have to be tailored to the specific crops grown and climatic conditions in a geographic region. For all conservation tillage practices, farmers need to understand and use appropriate management practices.

Following World War II, plow plant methods were refined by U.S. Department of Agriculture and land-grant university researchers, who found that the best soil conservation contribution of these methods was increased surface roughness to slow runoff. Although cool season crop residues were managed near the soil surface, some secondary cultivation was required for weed control even though selective herbicides were available.

Many other forms of conservation tillage emerged during the 1960's and 1970's, including ridge tillage for cold wet soils of the Corn Belt and strip till for restrictive horizon Ultisols of the Southeast. It was during this time period that the use of conservation tillage became widespread.

Conservation tillage has held a central role in agricultural program policy in the United States. Most of the 60-plus year history of Federal conservation programs emphasized the productivity benefits of reducing soil erosion. Beginning in the 1970's, interest developed in environmental issues. Conservation programs continued to target enhancements in soil productivity and net farm income, but the focus expanded to reduce off-farm impacts of agriculture on the environment (benefits accruing to society as a whole).

The following chapters will place in perspective the role that conservation tillage can play in sustaining agricultural productivity and improving the environment.

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II. Current Status of Conservation Tillage

- Conservation tillage was used on nearly 36 percent of planted acreage in 1996. This level has remained relatively unchanged over the past few years.

- The use of conservation tillage varies by crop and is dependent on site-specific factors including soil type, topsoil depth, and local climatic conditions.

- A number of economic, demographic, geographic, and policy factors have affected the adoption of conservation tillage. It is not possible to quantify exactly the impact of these factors on conservation tillage use.

- Management complexities and profitability are key factors impeding the adoption of conservation tillage.

The adoption of conservation tillage and the current extent of its use depend on a variety of economic, demographic, geographic, and policy factors. This chapter describes the evolution of the use of conservation tillage and provides some insights into the importance of economic and environmental considerations in a farmer's decision to use it.

Definition of Conservation Tillage

Conservation tillage has evolved from tillage practices that range from reducing the number of trips over the field to raising crops without primary or secondary tillage. Emphasis today is on leaving crop residues on the soil surface after planting rather than merely reducing the number of trips across the field, although the two practices are closely related.

As early as 1963, the Soil Conservation Service began tracking the number of cropland acres planted by minimum tillage, as it was referred to at the time. In 1963, minimum tillage was reportedly used on about 3.8 million planted acres or about 1 percent of total cropland. By 1967, acreage had doubled (Mannering et al., 1987).

One of the difficulties in tracking the trend in conservation tillage use was, until recently, the absence of a consistent definition of conservation tillage. Before 1977, minimum tillage described a conservation tillage practice primarily aimed at reducing the number of tillage trips over a field. A large portion of the acres on which minimum tillage was used would have had considerable amounts of residue after planting, but a significant portion also would not have met the current definition of conservation tillage (Schertz, 1988).

In late 1977, the Soil Conservation Service changed the term minimum tillage to conservation tillage and defined it as a form of noninversion tillage that retains protective amounts of residue mulch on the surface throughout the year. Types of conservation tillage included no-tillage, strip tillage, stubble mulching, and other types of noninversion tillage.

In early 1984, the Soil Conservation Service changed the definition of conservation tillage once again.[2] This definition is the industry standard (Conservation Technology Information Center, 1996):

> Conservation tillage is any tillage and planting system that maintains at least 30 percent of the soil surface covered by residue after planting to reduce soil erosion by water. Where soil erosion by wind is the primary concern, any system that maintains at least 1,000 pounds (per acre) of flat, small grain residue equivalent on the surface during the critical wind erosion period is considered conservation tillage. Two key factors influencing crop residue are (1) the type of crop, which establishes the initial residue amount and determines its fragility, and (2) the type of tillage operations prior to and including planting (table 2.1).[3]

Conservation Tillage Data

Sources of information on the use of conservation tillage are somewhat limited. Currently, there are two primary sources, both of which were used for this analysis. Because each is somewhat different, it is important to understand how the data are compiled.

The National Crop Residue Management Survey is produced by the Conservation Tillage Information Center (CTIC)[4] which, in 1983, was established with the primary objective to serve as a clearinghouse for gathering and sharing information on conservation tillage. CTIC is a division of the National Association of Conservation Districts and is supported by agribusiness, government (Federal and State), and other organizations. CTIC conducts an annual survey of crop residue management practices to provide accurate acreage and residue data to gauge the use of crop residue management systems among U.S. farmers. The survey, which includes all planting and tillage types, is conducted on a county-by-county basis that yields approximately 3,100 responses. The enumerators are a panel of local directors of U.S. Department of Agriculture program agencies (Natural Resources Conservation Service, Farm Service Agency, (formerly the Agricultural Stabilization and Conservation Service), and the Cooperative Extension Service and others knowledgeable about local crop residue management practices. These enumerators complete the survey each summer. The survey provides only information about crop residue management systems. It does not provide information on crop yields, production costs, input use, cropland erodibility classification, other production practices (e.g., crop rotations), or the costs of implementing any of the conservation tillage practices.

The *Cropping Practices Survey* (CPS) was conducted annually by the U.S. Department of Agriculture between 1990 and 1995. Annual data were collected on fertilizer and pesticide use, tillage systems employed, cropping sequences, cropland erodibility classification, is, and information on the use of other inputs and production practices. The survey covered corn, cotton, soybeans, wheat (winter, spring, and durum), and potatoes. Only selected States were surveyed, but about 80 percent of the total planted acreage for the surveyed crops was covered.

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[2] The definition was developed through a joint effort involving the Soil Conservation Service, the Economic Research Service, and the Agricultural Research Service of the U.S. Department of Agriculture, the Conservation Technology Information Center (CTIC), and private sector participants.

[3] The CTIC continues to use this definition for the sake of long term trend analysis. The Natural Resources Conservation Service no longer uses this definition.

[4] It was later renamed the Conservation Technology Information Center.

Five tillage systems, conventional tillage with moldboard plow, conventional tillage without moldboard plow, mulch tillage, ridge tillage, and no-tillage, were defined based on the use of specific tillage implements and their residue incorporation rates (Bull, 1993). The CPS was not designed to collect information on whether fields meet the conservation compliance requirements nor to reveal the costs of implementing conservation tillage practices.[5] While the CPS did collect information on tillage and planting implements used, it did not collect comprehensive machinery use information such as the type of tractor or its horsepower rating. No survey collects that information.

Trends in Conservation Tillage Use

The use of conservation tillage in the United States increased from 2 percent of planted acreage in 1968 to nearly 36 percent in 1996 (fig. 2.1), although there was little change in the last four years of that period. (Schertz, 1988 and CTIC).[6] A disaggregated view of the use of conservation tillage can be obtained by looking at specific crops and States/regions. Because the CTIC data are more comprehensive than the CPS data, CTIC data are used here to summarize conservation tillage adoption levels. CTIC data collection at the crop/State level based on a consistent definition of conservation tillage began only in 1989. Hence, the data reported start in that year.

U.S. cropland acreage that was conservation tilled increased from 26 percent (71.7 million acres) to 36 percent (103.8 million acres) from 1989-1996 but the increase differs by crop (table 2.2a and table 2.2b); conservation tillage is used mostly on soybeans, corn, and small grains. More than 40 percent of total corn and soybean planted acreage in 1996 was conservation tilled. Where double-cropping was used, nearly 70 percent of soybean acreage, 46 percent of corn acreage, and 37 percent of sorghum acreage employed conservation tillage systems.

Full-season corn is the most extensively grown crop in the United States, accounting for 27 percent (31.4 million acres) of total planted acreage in 1996. Currently, approximately 40 percent of planted acreage on which corn is grown is conservation tilled. Between 1995 and 1996, use of conservation tillage declined in Indiana, which produces relatively large amounts of corn,[7] and, to a lesser degree, in Ohio. Both States encountered unusually wet weather conditions at the time of planting in the spring. Because of that, more than 650,00 acres in Indiana alone (over 5 percent of total planted acreage) that were conservation-tilled in 1995 were reverted to reduced tillage and/or conventional tillage in 1996 (table 2.3). About a third of sorghum area was conservation tiled in 1996, but that percentage, for unexplained reasons was the lowest it had been since 1992.

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[5] In 1996, the CPS and the Farm Costs and Returns Survey (FCRS) were combined into the Agricultural Resource Management Study (ARMS) survey. The intention is to provide information on production practices and costs and returns. The ARMS survey provides more information on the costs of production and production characteristics associated with different tillage practices than did the CPS, thereby allowing researchers to identify the factors affecting a farmer's decision to use conservation tillage.

[6] Schertz estimates conservation tillage for the period 1968-1981. His data are taken from a variety of sources and adjusted for changes in the definition of conservation tillage.

[7] Nearly 47 percent of Indiana's planted acreage is in corn. Additionally, more than 7 percent of total corn planted acreage in the United States is in Indiana.

Cotton has the lowest proportion of conservation tillage, increasing from 3 to 10 percent between 1989 and 1996. Other important crops, like peanuts, potatoes, beets, tobacco, and vegetables, have also improved residue management and erosion control, even though their cultural practices preclude the use of conservation tillage. The fall in the use of conservation tillage on sorghum is not easily explainable

Kentucky leads the Nation in conservation tillage, with an adoption rate of 73 percent. Delaware, Iowa, Maryland, Missouri, Nebraska, and Tennessee all have between 50 and 63 percent of cropland conservation-tilled (table 2.3). Arizona, Florida, Massachusetts, Rhode Island, and Vermont all have adoption rates less than 10 percent. The Appalachian and Corn Belt regions lead in conservation tillage adoption with 48 and 46 percent, respectively, while the Delta, Southeast, Pacific, and Southern Plains have only between 18 and 23 percent (table 2.4).

The substantial fall in the use of conservation tillage in the Corn Belt and Lake States regions between 1993 and 1994 reflects the heavy rains and flooding in 1993 that destroyed crop acreage (table 2.4). Nearly 5 million fewer acres were planted in 1993 than in 1992 and 1994. Most of this land was returned to production in 1994, but rills and gullies on the surface and sand and soil deposits on the bottomlands forced farmers to till the soil more. Much of the decline in mulch tillage in 1994 is attributed to this (table 2.5). Thus, the use of conservation tillage in Illinois fell by 16.3 percentage points between 1993 and 1994 while Kansas, Minnesota, Ohio, and Wisconsin experienced similar, although less precipitous, declines (table 2.3).

Another important factor leading to the decline in conservation tillage in the Corn Belt in 1994 was the absence of a government set-aside program. Previously idled acres that were returned to production were tilled using conventional practices (U.S. Environmental Protection Agency, 1996).

The largest regional growth in the use of conservation tillage between 1989 and 1996 occurred in the Northern Plains, the Corn Belt, and the Lake States (table 2.4). This growth was mostly a function of conservation compliance (Williams et al., 1989, Esseks and Kraft, 1993, and Hyberg and Johnston, 1997). In the Northern Plains, recent increases in the use of conservation tillage reflect the rise in the use of such systems to plant and manage small grains (e.g., wheat) as well as corn.

The largest increase in the use of conservation tillage in the past few years occurred in South Dakota. In 1996 alone, more than 1 million additional acres were conservation-tilled. These additional acres were not exclusively switched from conventional to conservation tillage. Planted acreage in South Dakota increased by approximately 1.5 million acres between 1995 and 1996 while the number of fallow acres fell by more than 500,000. The main reason that fallow acres decreased in South Dakota appears to be because of the additional moisture that was retained as a result of using no-tillage. This allowed farmers to plant a crop (principally soybeans) instead of leaving the land fallow (Beck, 1996).

Mulch tillage (table 2.1) continues to be the dominant type of conservation tillage (table 2.5) although use of no-tillage has increased rapidly. Mulch tillage accounted for 57 percent of conservation tillage and was used on 20 percent of the Nation's cropland in 1996. No-tillage accounted for 41 percent of conservation tillage, used on 15 percent of the Nation's cropland, while ridge tillage was used on only about 1 percent of the cropland in 1996. Over the past few years, there has been a slight increase in the use of no-tillage relative to mulch tillage.

Results from the *Cropping Practices Survey* (CPS) can give insights into the use of conservation tillage not available from the *National Crop Residue Management Survey* of the CTIC.[8] The CPS focuses on only a limited number of agricultural commodities, but does include sufficient information to estimate the use of conservation tillage by land classification, or highly erodible land (HEL) versus nonhighly erodible land (NONHEL). The use of conservation tillage on HEL and NONHEL for corn, soybeans, and all wheat (winter, spring, and durum) exhibits an identifiable upward trend from 1989-1993 (Fig. 2.2)[9,10]. The trend in the use of conservation tillage on NONHEL emulates that on HEL. Conservation tillage, however, is used about 8 to 10 percent more extensively on HEL than on NONHEL. When total planted acreage for major field crops is considered, about 28 percent of conservation tillage occurs on HEL, while almost 72 percent of conservation tillage occurs on NONHEL. Therefore, conservation compliance is not the sole force motivating the adoption of conservation tillage even though conservation tillage has been most vigorously promoted for its ability to control soil erosion. Economic factors are clearly impacting farmers' decisions to adopt and use conservation (*Triazine Network News, 1996*).

For corn and soybeans, the growth in the use of conservation tillage has been greater on HEL than on NONHEL, while for wheat there has been little aggregate change from 1989-1995 (table 2.6). Approximately 15 percent of corn acres surveyed in the CPS in 1995 was designated as HEL, with 60 percent of that acreage planted using conservation tillage. Nearly 14 percent of the land on which soybeans were grown was designated as HEL and 68 percent of that land used conservation tillage in 1995. Only about a fourth of wheat-planted acreage used conservation tillage in 1995 while over 38 percent of the cropland was designated as HEL.

The CPS also includes questions about the length of time production practices have been used. The responses indicate that most farmers have been using conservation tillage for a relatively short period of time. In 1995, for example, corn farmers who used conservation tillage had on average been using it for only 1.5 years. For soybean and wheat farmers, the averages were 2.3 and 0.9 years, respectively. Thus, farmers do not have extensive experience with the management problems that arise from using conservation tillage for these crops.[11] This, in part, can help explain why Indiana farmers, when confronted with wet soil conditions in 1996, reverted to well-known conventional tillage practices.

The crop residue left on the field is, not surprisingly, substantially greater for conservation tillage than it is for conventional tillage. For example, in 1995, the crop residue left after the corn harvest was 55.3 percent for conservation tillage versus 13.2 percent for conventional tillage. On HEL, the residue cover was somewhat higher at 65 percent for conservation-tilled

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[8] This examination of the trend in the use of conservation tillage is not meant to be exhaustive; rather, it illustrates general trends in conservation tillage in U.S. agriculture. The reader interested in specific details for individual States and/or categories of conservation and conventional tillage practices is referred to Conservation Technology Information Center's *National Crop Residue Management Survey*, Bull and Sandretto (1996), and USDA's Economic Research Service (1997).

[9] Consistent data by land class designation are currently available only for this period.

[10] Cotton data are not reported. In 1995, conservation tillage was used on less than 2 percent of highly erodible cotton acreage and on less than 1 percent of nonhighly erodible acreage.

[11] This factor will be dealt with in greater detail in the next chapter.

cropland. For soybeans and wheat, the percentages of residue cover were 63 and 45 percent, respectively versus 16.5 and 11.3 percent for conventional tillage. On HEL conservation-tilled cropland alone, the values were 71 and 47.1 percent residue cover for soybeans and wheat, respectively. The relative amounts of crop residue left on the field for these crops has remained roughly constant over the period 1989-1995.

Factors Affecting Conservation Tillage Adoption and Use

Farmers in general tend to make production practice changes slowly. The adoption process generally can be viewed as having five stages (Nowak and O'Keefe, 1992). Initially, farmers are unaware of a new practice (stage 1). They become aware of new practices through various sources, including neighbors, farm publications, mass media, County Extension Service agents, chemical dealers, and crop consultants (stage 2). Farmers then evaluate the practice in terms of their own operation through educational sources such as demonstration projects, talking with agents, and talking with neighbors who have tried the practice (stage 3). Farmers may then test the practice on part of their farm (stage 4). The ability of a practice to be tested on part of the farm enhances its potential for adoption (Office of Technology Assessment, 1990 and Nowak and O'Keefe, 1995). Finally, full adoption occurs if the practice is found to be better than what the farmers are currently using (stage 5).

A variety of economic, demographic, geographic, and policy variables affect the adoption and use of conservation tillage in the United States.[12] The rate of adoption (diffusion) of a new technology—e.g., conservation tillage—determines the rate of technological change. The first empirical assessment of the diffusion of a new technology was applied to hybrid corn (Griliches, 1957). The diffusion follows an innovation cycle, which starts with efficient producers first introducing the new technology that requires a threshold level of technical skill for profitable use. As skill levels of other farmers increase through experience, the new technology is more widely adopted. The time path of adoption of the new technology can be analytically derived as a function of the distribution of technical ability among producers and the rate of change in technical skill (Kislev and Schori-Bachrach, 1973). Adoption is also a function of exogenous factors, and these factors will retard or accelerate the rate of adoption. Investment costs associated with the adoption of the new technology will have an important influence on a farmer's choice. Government policy in the form of conservation compliance is an example of an exogenous factor that would be expected to accelerate the rate of adoption of conservation tillage (Batte, 1993). Yet another exogenous consideration is what is nominally referred to as learning by doing (Alchien, 1959, Rosen, 1972, and Dudley, 1972). When

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[12] Because of the nature of the data available and their limitations, however, it is generally not possible to quantify precisely the impact that these factors have on conservation tillage use. Among the more serious data limitations are the availability of only a relatively short time series, incomplete measurement of all of the relevant variables for the times series that are available, measurement error in the data, absence of panel data, and difficulty in separating the impact of government policy (conservation compliance) from varying climatic and economic conditions. With regard to the first issue, consistent data on conservation tillage date only to the late 1980's. Six or seven years' worth of annual observation is typically inadequate to estimate a formal structural model when there are more that just a few factors affecting the dependent variable (the relative use of conservation tillage). Of the time series data that are available, information on coincident climatic conditions and relevant economic variables are not collected in any sort of useable way. The changing definition of conservation tillage over the longer period has introduced measurement error of the dependent variable. The absence of panel data makes it impossible to monitor the behavior of any group of farmers over time. Consequently, because of these data limitations, in the review that follows, many of these factors affecting conservation tillage use will be discussed, but it is not feasible to quantify their relative importance in influencing the trend in the use of conservation tillage.

specialized management skills are required for production, owner/operators will gain proficiency with experience; that is, they learn by doing.

Central to the question of adoption of a new technology is the issue of heterogeneity: why farmers differ in their willingness to adopt a new technology. Much of the literature concerning the adoption of new technologies focuses on this issue (Antle and McGuckin, 1993, and Westra and Olson, 1997). Among the reasons suggested for differences among farmers in their willingness to adopt conservation tillage is their by entrepreneurial ability, risk preferences, and availability of complementary inputs (Feder et al., 1985). The entrepreneurial or managerial requirements of conservation tillage are more complex than for conventional tillage. Management skills, in fact, dominate the successful use of conservation tillage (U.S. Department of Agriculture, AH-712, 1997). The successful adoption of soil-conserving tillage systems normally requires a higher level of management skills to carry out the proper timing and placement of nutrients and pesticides. Conservation tillage allows for less opportunity to correct mistakes or adjust to changed circumstances once the growing season is underway. Adoption of a new technology by a farmer always involves a degree of risk and uncertainty concerning its impact on output. The risk associated with the adoption of a new technology can affect the enterprise in a number of ways. Just and Zilberman (1983) argued that producers with large farms are more likely to adopt new technologies because of diversification and that the willingness to adopt new technologies depends on the similarity in the inputs between the existing and the new technology. Finally, new technologies must be integrated into the availability of existing inputs. For conservation tillage, this implies that any conservation tillage system must be compatible with, for example, the soil characteristics and climatic conditions on the farm (Nowak, 1984, 1992).

In the context of the diffusion of conservation tillage as a new technology (production practice), a number of studies provide some insights into the factors that affect the adoption of conservation tillage. Because there is considerable redundancy in the results of the studies, an exhaustive survey will not be provided. Pagoulatos et al. (1989), using an erosion-damage function analysis for corn grown in Kentucky, found that the decision to convert to conservation tillage from conventional tillage is dependent on the price of output, the discount rate (with a higher discount rate leading to a slower adoption of conservation tillage), and the capital cost of conversion. Large capital costs for new machinery serve as a deterrent to adoption of conservation tillage.

Uri (1997) used a two-stage decision model econometrically estimated for corn produced in the United States in 1987. The data came from the Farm Costs and Returns Survey (FCRS) conducted by the U.S. Department of Agriculture.[13] Uri found that cash grain enterprises were more likely than other farm types to adopt conservation tillage. The slope of the cropland was an important factor (the greater the slope,[14] the greater the likelihood of conservation tillage adoption), as was average rainfall (the greater the rainfall, the greater the likelihood of conservation tillage adoption), but not average temperature. A number of factors, including expenditures on some inputs and farm owner/operator characteristics, were found not to be associated with the adoption or nonadoption of the conservation tillage production practice.

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[13] The last year for which the FCRS collected data sufficient to permit estimation of a production function was 1987. In subsequent years, the survey was scaled back due to concern about respondent burden.

[14] Slope is one component of the Universal Soil Loss Equation and is used in computing the erodibility index. The value of the erodibility index determines whether the cropland is classified as HEL. See the appendix to chapter 3 for details.

For example, the age and education of the farmer/operator was not associated with the adoption of conservation tillage. The productivity of the soil, as measured by average yield across farms in a county, had no identifiable impact on the decision to adopt conservation tillage. The texture of the soil, the total acres planted, the number of acres in the acreage reduction program, the extent of irrigation, and the proportion of acres not receiving any pesticide treatment likewise were not associated with the adoption of conservation tillage on corn acreage.

Gray et al. (1996) in references used a simulation model to compare the adoption of conservation tillage systems to conventional tillage systems for wheat production in western Canada. Crop yield and the price of burndown herbicide (the herbicide used to eliminate vegetation prior to planting) were key determinants to the shortrun profitability of adopting conservation tillage. The price of fuel was also important, although less so.

Carter and Kunelius (1990), analyzing data from Atlantic Canada, found that some soil types were simply not suitable for conservation tillage.[15] The soils required a high degree of cultivation to maintain their structure and regular tillage to ensure adequate crop productivity. Moreover, climatic constraints such as a short growing season, cold temperatures, and excessive precipitation could influence the choice of a conservation tillage system.

The greater risk associated with the use of conservation tillage has been shown to be a deterrent to the adoption of conservation tillage in a number of studies. Risk in these studies is typically defined as variability in yields or variability in net returns. Thus, Mikesell et al. (1988), using a simulation model, evaluated the expected net returns and risk of alternative tillage systems for a 640-acre grain farm in northeastern Kansas. Conservation tillage systems had slightly higher expected incomes but were more risky. A risk-averse farmer would prefer conventional tillage to conservation tillage. Williams et al. (1988) in references using a simulation model found that conservation tillage used in grain sorghum production had higher expected net revenues but greater risk than conventional tillage.

Westra and Olson (1997) estimated a structural model based on survey responses for farmers in two counties in Minnesota. Their results suggest that larger farms are more likely to use conservation tillage. Also, if the owner/operator is relatively more concerned about erosion, the probability of adopting conservation tillage is greater. The greater complexity associated with the use of conservation tillage requiring greater management skill is identified as a deterrent to the adoption of conservation tillage.

The consensus of the studies cited here plus others[16] is that the relative economic performance of any conservation tillage practice depends on a number of site-specific factors. The degree to which the farmer is risk averse, the soil type, the topsoil depth, the choice among cropping systems, the farmer's level of managerial expertise, and local climatic conditions have all been identified as important variables. Consequently, a farmer's decision to use conservation tillage will depend on these site-specific and operator-specific factors. The aggregate effect of these site-specific factors superimposed on operator characteristics and the basic diffusion model for a new technology have contributed to the evolution of the trend in conservation tillage use in

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[15] The soil types were not identified.

[16] For a more extensive review, see Fox et al. (1991) and Roberts and Swinton (1996).

the United States. Site-specific factors impact both the rate of adoption of conservation tillage and the ultimate extent of its use.

Conclusion

The adoption of conservation tillage in the United States had a pronounced upward trend until 1993. Since that time, the percentage of the planted acreage using conservation tillage practices has exhibited a very slight upward trend. One of the challenges in examining the trend in conservation tillage use is to explain its evolution in terms of economic and geographic factors and government policy. While it is difficult to precisely quantify the impact of any specific factor, a number of empirical studies suggest that different economic and geographic variables do affect decisions to adopt conservation tillage, and, ultimately, the extent of its use. Relative performance—net private benefits—matters the most. Consequently, any attempt to increase the adoption of conservation tillage should address the relative performance issue.

The following chapter examines the economic and environmental effects of more extensive use of conservation tillage in the United States.

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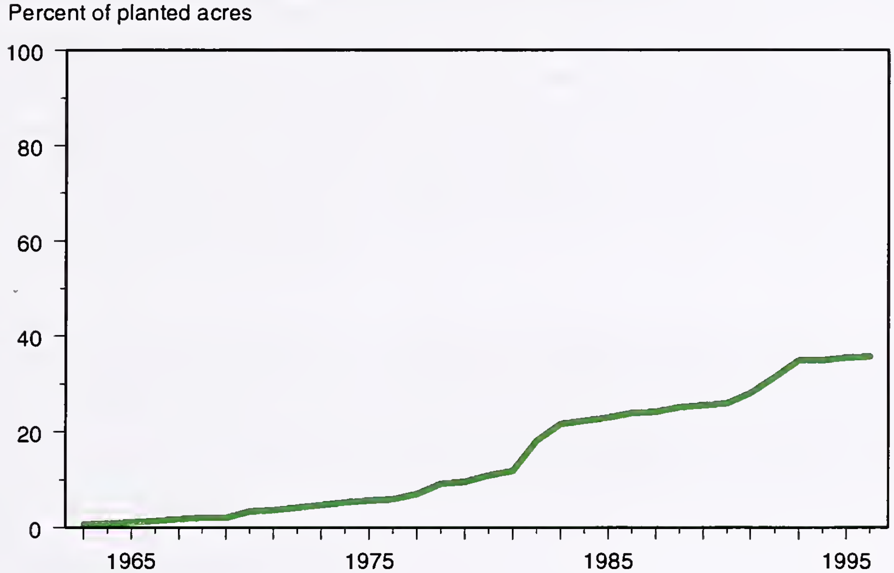
Figure 2.1

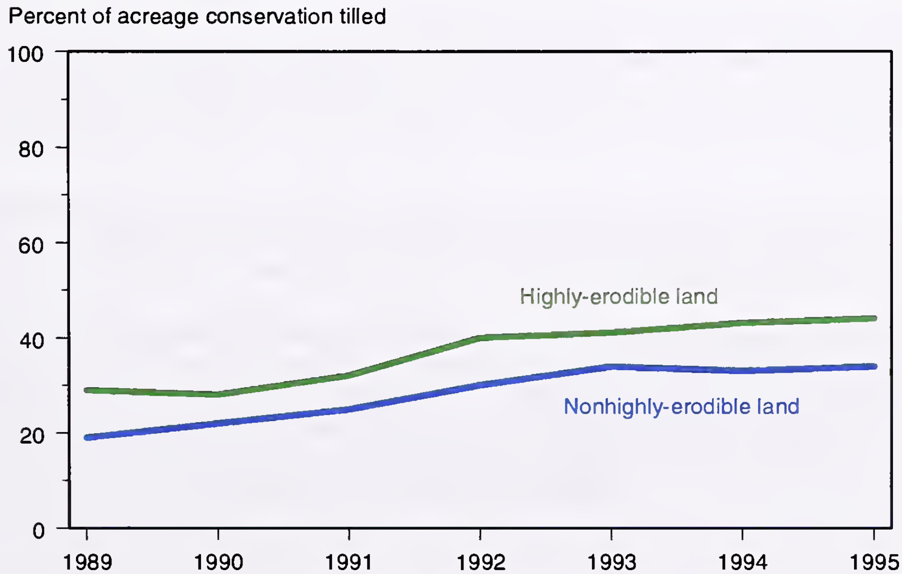
Planted acres on which conservation tillage is adopted



Source: Schertz (1988) and CTIC

Figure 2.2

Conservation tillage use on major field crops by land classification



Source: Cropping Practices Survey

Table 2.1—Tillage System Definitions

Crop Residue Management (CRM)—A year-round conservation system that usually involves a reduction in the number of passes over the field with tillage implements and/or in the intensity of tillage operations, including the elimination of plowing (inversion of the surface layer of soil). CRM begins with the selection of crops that produce sufficient quantities of residue to reduce wind and water erosion and may include the use of cover crops after low residue-producing crops. CRM includes all field operations that affect residue amounts, orientation, and distribution throughout the period requiring protection. The amounts of residue cover needed at specific sites are usually expressed in percentage but may also be in pounds. Tillage systems included under CRM are conservation tillage (no-tillage, ridge tillage, and mulch tillage) and reduced tillage.

Conservation Tillage—Any tillage and planting system that maintains at least 30 percent of the soil surface covered by residue after planting to reduce soil erosion by water. Where soil erosion by wind is the primary concern, any system that maintains at least 1,000 pounds (per acre) of flat, small-grain residue equivalent on the surface during the critical wind erosion period. Two key factors influencing crop residue are (1) the type of crop, which establishes the initial residue amount and determines its fragility, and (2) the type of tillage operations prior to and including planting.

Conservation Tillage Systems include:

> *Mulch tillage*—The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Weed control is accomplished with herbicides and/or cultivation.
>
> *Ridge tillage*—The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with herbicides and/or cultivation. Ridges are rebuilt during cultivation.
>
> *No-tillage*—The soil is left undisturbed from harvest to planting except for nutrient injection. Planting or drilling is accomplished in a narrow seedbed or slot created by coulters, row cleaners, disk openers, in-row chisels, or roto-tillers. Weed control is accomplished primarily with herbicides. Cultivation may be used for emergency weed control.

Reduced-till (15-30 percent residue)—Tillage types that leave 15-30 percent residue cover after planting, or 500-1,000 pounds per acre of small grain residue equivalent throughout the critical wind erosion period. Weed control is accomplished with herbicides and/or cultivation.

Conventional-till (less than 15 percent residue)—Tillage types that leave less than 15 percent residue cover after planting, or less than 500 pounds per acre of small-grain residue equivalent through the critical wind erosion period. Generally includes plowing or other intensive tillage. Weed control is accomplished with herbicides and/or cultivation.

Source: Conservation Technology Information Center (1996).

Table 2.2a—Trends in conservation tillage use by crop

Crop	1989	1990	1991	1992	1993	1994	1995	1996
	Percent of planted acres conservation tilled							
Corn, dc	48.8	51.6	53.4	50.5	48.1	53.2	53.5	46.4
Corn, f	32.0	32.1	34.7	38.9	43.4	40.4	41.1	40.1
Cotton	3.2	4.8	6.1	7.6	10.0	10.7	10.0	10.3
Fallow	27.1	6.3	28.8	32.0	21.0	24.2	35.4	36.7
Forage	23.1	22.5	20.9	22.0	22.4	24.2	23.4	25.0
Grain, fsd	27.7	27.0	28.5	28.5	29.9	31.0	32.2	32.4
Grain, ssd	19.9	20.8	24.0	25.5	28.3	30.8	29.9	30.4
Other	8.0	9.4	10.2	10.7	12.7	15.4	14.9	15.2
Permanent pasture	42.2	35.6	37.0	34.8	33.4	40.0	34.8	37.9
Sorghum, dc	37.3	42.5	46.4	46.3	41.7	50.6	43.6	37.1
Sorghum, f	29.7	29.9	32.1	29.1	34.7	34.8	36.0	32.2
Soybeans, dc	55.3	27.5	62.8	63.4	64.7	66.3	69.6	69.6
Soybean, f	26.8	27.2	30.5	38.9	47.2	46.3	48.6	49.0
Average	26.0	23.9	28.3	31.4	33.8	34.1	35.5	35.9

On crop types: dc = double crop
f = full season crop
fsd = fall seeded
ssd = spring seeded

Source: Conservation Technology Information Center, annual surveys.

Table 2.2b—Trends in conservation tillage use by crop

Crop	1989	1990	1991	1992	1993	1994	1995	1996
	Million acres							
Corn, dc	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.6
Corn, f	23.1	23.5	25.6	30.1	31.8	31.3	29.3	31.4
Cotton	0.4	0.6	0.8	0.9	1.4	1.5	1.6	1.5
Fallow	6.8	7.5	7.8	2.8	5.1	6.5	9.0	8.4
Forage	1.6	1.6	1.6	1.8	1.8	2.0	1.9	1.8
Grain, fsd	14.2	14.9	14.8	14.6	15.4	15.6	15.7	16.3
Grain, ssd	8.1	8.0	8.8	9.4	10.1	10.9	10.3	11.1
Other	1.7	2.0	2.4	2.4	3.1	3.9	3.8	3.7
Permanent pasture	1.8	2.2	1.5	1.4	1.4	1.4	1.2	1.0
Sorghum, dc	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sorghum, f	3.4	3.2	3.3	3.5	3.5	3.2	3.1	3.5
Soybeans, dc	3.4	3.9	4.1	3.7	3.5	3.8	3.9	4.1
Soybean, f	15.2	15.0	17.1	21.5	26.0	26.5	28.6	29.7
Total planted acres	71.7	73.2	79.1	88.7	97.2	99.3	98.9	103.8

On crop types: dc = double crop
f = full season crop
fsd = fall seeded
ssd = spring seeded

Source: Conservation Technology Information Center, annual surveys.

Table 2.3—Trends in conservation tillage use by State

State	1989	1990	1991	1992	1993	1994	1995	1996
	Percent of planted acres conservation tilled							
Alabama	14.9	12.3	13.4	18.1	19.6	20.1	23.0	26.3
Arkansas	8.5	11.4	9.6	9.6	11.9	13.1	13.2	15.2
Arizona	0.8	1.0	1.0	1.0	2.8	4.2	4.5	5.3
California	7.1	7.0	7.4	14.4	13.2	16.6	16.0	17.1
Colorado	20.8	17.4	27.3	20.6	22.8	26.1	22.9	31.0
Connecticut	14.1	14.9	11.9	18.9	18.2	16.0	16.9	16.9
Delaware	53.0	36.2	66.3	58.6	66.0	61.7	62.3	62.6
Florida	15.7	5.1	4.1	2.4	5.6	8.4	8.4	9.3
Georgia	20.3	20.1	17.2	18.2	18.4	18.4	15.4	15.6
Iowa	29.5	33.0	31.9	43.7	50.4	51.0	52.2	50.5
Idaho	26.2	24.2	26.5	26.6	30.2	31.1	32.6	30.4
Illinois	36.7	35.4	42.5	48.0	53.6	37.3	39.8	40.5
Indiana	42.2	22.2	30.1	36.5	40.6	46.5	50.5	43.5
Kansas	29.4	22.2	31.7	31.1	36.7	34.0	36.0	35.7
Kentucky	59.3	42.8	59.8	62.8	67.2	67.2	69.1	72.5
Louisiana	7.1	10.6	13.6	14.0	14.6	17.7	16.4	20.1
Massachusetts	4.4	6.2	6.1	6.6	6.9	8.3	8.2	8.2
Maryland	54.5	38.9	51.5	52.5	56.2	58.5	59.5	63.2
Maine	40.9	35.4	39.5	17.7	42.6	26.4	22.8	21.4
Michigan	23.4	28.2	31.2	35.5	41.7	44.8	46.1	48.2
Minnesota	17.6	18.3	19.5	22.1	27.1	23.8	23.5	25.7
Missouri	35.5	34.8	40.5	43.9	48.0	50.2	50.8	50.1
Mississippi	22.2	15.3	22.2	26.9	28.8	28.6	28.2	28.6
Montana	22.4	20.6	28.4	30.0	33.6	38.4	41.5	42.4
North Carolina	18.4	12.4	16.3	17.2	17.4	21.5	23.3	23.5
North Dakota	18.3	17.3	25.2	26.5	28.3	32.7	29.9	29.4
Nebraska	36.9	38.2	44.6	48.6	55.4	57.9	57.7	58.0
New Hampshire	9.1	10.4	8.3	7.8	9.0	9.9	13.4	13.4
New Jersey	26.9	16.2	23.3	30.2	32.8	41.1	35.4	33.8
New Mexico	19.9	12.8	13.5	21.7	28.0	29.4	29.1	30.9
Nevada	52.2	49.3	49.2	44.6	32.3	32.3	32.3	36.5
New York	17.4	16.3	17.2	19.3	20.6	20.9	20.8	21.2
Ohio	26.9	29.6	33.7	39.1	49.4	45.7	47.0	45.6
Oklahoma	28.1	28.8	28.8	22.4	22.4	22.2	23.0	21.1
Oregon	33.2	19.9	24.2	22.9	22.9	28.2	24.3	27.7
Pennsylvania	36.8	35.8	34.9	33.0	36.3	37.0	36.5	38.6
Rhode Island	5.4	11.1	8.1	5.3	6.2	3.1	3.2	3.2
South Carolina	16.0	6.8	18.5	19.8	24.0	26.0	26.7	22.3
South Dakota	24.1	22.6	25.7	31.3	33.7	35.6	34.7	38.0
Tennessee	31.1	29.9	37.0	45.0	49.2	57.0	54.6	56.3
Texas	20.5	20.7	20.5	20.9	22.8	25.9	25.1	23.8
Utah	17.9	13.6	20.2	22.5	23.8	23.4	25.8	30.0
Virginia	48.7	38.5	50.9	44.4	44.2	45.3	46.4	46.8
Vermont	3.4	3.6	7.7	4.4	5.3	5.9	5.1	4.4
Washington	19.5	12.2	14.5	18.5	18.0	20.8	22.0	22.5
Wisconsin	18.1	19.4	21.3	23.8	29.6	28.6	31.3	31.1
West Virginia	33.8	37.0	37.8	39.1	45.1	44.1	44.6	45.9
Wyoming	25.8	13.8	19.9	19.9	17.1	16.4	15.9	26.0

Source: Conservation Technology Information Center, annual surveys.

Table 2.4—Trends in conservation tillage use by U.S. Department of Agriculture regions

Region	1989	1990	1991	1992	1993	1994	1995	1996
	Percent of planted acres conservation tilled							
Appalachian	37.4	29.1	38.1	40.8	43.5	45.8	46.7	48.4
Corn Belt	34.1	31.9	36.2	43.4	49.3	45.4	47.4	45.9
Delta States	12.1	12.3	14.2	15.6	17.3	18.7	18.2	20.2
Lake States	18.9	20.5	22.3	25.2	30.6	28.9	29.8	31.4
Mountain	21.7	18.8	25.6	24.4	27.9	29.8	31.3	34.6
Northeast	34.5	29.1	33.8	33.6	36.9	37.8	37.4	38.8
Northern Plains	26.9	24.4	31.7	33.9	37.9	39.2	38.8	39.2
Pacific	16.0	11.5	13.4	17.2	16.3	20.2	19.6	21.1
Southeast	17.5	13.1	13.6	15.1	17.2	18.9	18.3	18.4
Southern Plains	22.8	23.2	22.9	21.3	22.7	24.9	24.5	23.1

Regional composition:
Appalachian (WV, KY, NC, TN, VA)
Corn Belt (IA, MO, IL, IN, OH)
Delta States (AR, LA, MS)
Lake States (MN, WI, MI)
Mountain (ID, MT, WY, NV, UT, CO, AZ, NM)
Northeast (ME, PA, NH, CT, NJ, NY, MD, MA, RI, DE, VT)
Northern Plains (ND, SD, NE, KS)
Pacific (WA, OR, CA)
Southeast (AL, GA, SC, FL)
Southern Plains (OK, TX)

Source: Conservation Technology Information Center, annual surveys.

Table 2.5—Trends in conservation tillage use by type

	Percent of total crop			Percent of total conservation tillage		
	no-till	ridge till	mulch till	no-till	ridge till	mulch till
1989	5.5	0.9	17.4	21.3	3.4	67.0
1990	6.5	1.0	16.9	27.1	4.1	70.6
1991	7.5	1.0	17.4	26.5	3.7	61.4
1992	9.9	1.1	19.0	31.7	3.6	60.5
1993	12.0	1.1	20.7	35.4	3.3	61.3
1994	13.2	1.1	19.8	38.8	3.3	57.9
1995	14.4	1.1	20.0	40.6	3.1	56.3
1996	14.5	1.1	20.2	40.5	3.0	56.5

Source: Conservation Technology Information Center, annual surveys.

Table 2.6—Tillage systems used in field crop production on highly erodible land, 1989-1995

Crop/tillage type/unit	1989	1990	1991	1992	1993	1994	1995
Corn - million planted acres	10.5	12.7	13.3	12.5	11.3	11.9	11.0
Conventional (%)	67	68	60	49	44	44	40
Conservation tillage (%)	33	32	40	51	56	56	60
Soybeans - million planted acres	6.3	8.3	8.3	7.9	8.4	8.6	8.8
Conventional (%)	72	67	55	46	37	35	32
Conservation tillage (%)	38	33	45	54	63	65	68
Wheat - million planted acres	10.0	14.1	13.0	14.7	16.4	15.7	16.1
Conventional(%)	76	76	82	73	75	77	74
Conservation tillage(%)	24	24	18	27	25	23	26

Source: USDA, Economic Research Service, *Cropping Practices Survey*

Table 2.7—Tillage systems used in field crop production on nonhighly erodible land, 1989-1995

Crop/tillage type/unit	1989	1990	1991	1992	1993	1994	1995
Corn - million planted acres	41.0	43.2	44.5	46.9	43.4	48.6	44.8
Conventional (%)	80	75	72	64	61	61	63
Conservation tillage (%)	20	25	28	36	39	39	37
Soybeans - million planted acres	39.3	36.6	38.7	37.9	41.5	42.7	43.9
Conventional (%)	78	75	68	63	55	54	52
Conservation tillage (%)	22	25	32	37	45	46	48
Wheat - million planted acres	36.5	40.2	35.0	40.0	37.9	37.1	35.9
Conventional(%)	86	83	86	82	85	87	80
Conservation tillage(%)	14	17	14	18	15	13	20

Source: USDA, Economic Research Service, *Cropping Practices Survey*

- The use of every production system, including conservation tillage, has economic and environmental consequences. A system designed to satisfy environmental goals cannot be fairly evaluated on private economic criteria alone.

- The economic benefits of the adoption of conservation depend on site-specific factors including soil characteristics, local climatic conditions, cropping patterns, and other attributes of the overall farming operation. While it is possible to draw some general inferences about components of economic returns and costs, a comprehensive assessment of the net private benefits from greater use of conservation tillage is not feasible.

- Switching the remaining 22.4 million acres of highly erodible land that is currently conventionally tilled to conservation tillage will increase social benefits by about $49.6 million annually.

- Nonquantifiable social benefits associated with conservation tillage include improved wildlife habitat and reduced atmospheric emissions.

Growing concerns about the impact of agricultural production on the environment has caused an increase in the use of conservation tillage, which frequently reduces surface water contamination and may enhance soil quality. Many conservation tillage practices, designed to attain environmental objectives, cannot be fairly evaluated on productivity criteria (net private benefits) alone. In this chapter, the economic and environmental issues associated with the adoption of conservation tillage are explored.

Historically, productivity criteria were the sole factors considered in comparing and contrasting alternative production technologies. Since the late 1940's, research on crop production focused on reducing labor requirements and increasing yields per unit of land (Hayami and Ruttan, 1985). Economic evaluations of a new production technology were primarily concerned with the effects of the new technology on profitability. Yield increases by themselves may not increase profits, so the central issue for farmers evaluating a new practice was whether the value of the yield increase justified the costs incurred to obtain it. Farmers would consider whether net farm income (net private benefits) would increase and would project explicit fixed and variable costs and expected prices and yields. Farmers also would include the implicit or subjective costs associated with switching production technologies. Calculations of net farm income would also include any government program payments contingent upon the adoption of a new production technology such as conservation tillage.[17]

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[17] Note that the issue of equity, an important part of the historical justification for soil conservation programs (Strohbehn, 1986), is not addressed in this report. While soil conservation programs originated during the 1930's and had employment and income support objectives (Rasmussen, 1982), comparing conservation tillage to conventional tillage with respect to equity goals involves too many subjective factors to be included here.

Measuring the Benefits and Costs of Conservation Tillage

Profitability and environmental impact are the most salient performance criteria for evaluating the impact of conservation tillage adoption. Profitability is the main criteria for private economic (net private benefits) decisions, while the environmental impact criteria compares the net social benefits of the different production practices.

Every production practice, including conservation tillage, has positive or negative environmental consequences that may involve air, land, water, and/or the health and ecological status of wildlife. The negative impacts associated with agricultural production, and the use of conventional tillage systems in particular, include soil erosion, energy use, leaching and runoff of agricultural chemicals, and carbon emissions. As with profitability, it is not solely average environmental effects that are important but also the stability of these effects.

As conservation tillage is further adopted, its impact will be compared with the conditions associated with the use of conventional tillage. Conventional tillage practices typically involve the use of intensive tillage and generally leave less than 30-percent crop residue cover on the soil after harvest. Different types of plows include the moldboard plow, chisel plow, subsoiler, disk plow, offset disk, and blade plow (Dickey, 1992).[18] Since conventional farming practices are continually evolving and vary geographically, the point of comparison must be typical of common practices for the time and location of the assessment. The relative gain from adopting conservation tillage will depend on the system from which the farmer switched.

The Economic Benefits and Costs to Farmers of Conservation Tillage Adoption

A farmer who chooses conservation tillage over conventional tillage does so in hopes that it will maximize net farm income (profit) and/or mitigate risk.[19] Consequently, in assessing the economic benefits and costs of conservation tillage versus conventional tillage, it is necessary to evaluate each of the components that contribute to net farm income and risk. These components include yield, expected output prices, and inputs used in the production of the agricultural commodities.[20]

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[18] On only 12 percent of the planted acreage for major field crops in the United States in 1995 was a moldboard plow used under conventional tillage (USDA Economic Research Service, 1997).

[19] An integral part of the private conservation tillage adoption choice is the decision at what level to control soil erosion. A formal statement of this decision has been developed in a number of sources (Foltz et al., 1995, McConnell, 1983, and Miranowski, 1993). The essence of these statements is that, in selecting the most economically efficient production practice where soil erosion control is an argument in the objective function, efficiency is achieved when soil loss occurs at the level where the value of the returns associated with additional soil loss equals the implicit cost of losing the additional soil (i.e., marginal forgone future returns). Thus, higher levels of yield loss per unit of soil loss will lower total soil loss during a given period. If a farmer places a relatively higher value (i.e., greater forgone yield) on a unit of topsoil, a greater effort will be made to reduce soil loss than with a lower value. Additionally, if agricultural output prices are increasing or are expected to increase over time, a more soil-conserving practice will be adopted, all other things equal, since the value of returns associated with soil loss will be higher.

[20] The revenue a farmer expects to receive from producing a crop is a function of expected yield and expected output price. The latter is not affected by the choice of tillage practice and so it is not discussed here. The higher the output price, the more influential yield differences between tillage practices become.

Yield

Yield is a function of many site-specific factors, including soil characteristics, local climatic conditions, cropping patterns, and other attributes of the overall farming operation. Conservation tillage can affect soil characteristics such as structure, organic matter content, and soil microbial populations that influence the movement of water in and through the soil, thereby potentially resulting in an increase in yield (Bruce et al., 1995, Ismail et al., 1994, Office of Technology Assessment, 1990, and Paudel and Lohr, 1996). Additionally, enhanced water infiltration associated with greater surface residue provides additional soil moisture that can benefit crops during periods of low rainfall (Baker, J.,1987, and Wauchope, 1987).

Yield benefits associated with the continuous use of conservation tillage take a relatively long time, perhaps a minimum of 10 years on some soils and under certain climatic conditions, to realize fully any potential yield effects associated with improved soil characteristics such as soil tilth (Hudson and Bradley, 1995, Ismail et al., 1994, Lal et al., 1990, Olson and Senjem, 1996, Zobeck et al., 1995). [21] Moreover, a single soil-disturbing tillage activity may eliminate any improvement in soil characteristics that had been realized (University of Illinois Agricultural Extension Service, 1997).[22]

The effect of conservation tillage on yield is not unequivocal. Before elaborating on this, two points need to be made. First, since conservation tillage consists of different subclasses, yield effects will vary not only by site-specific characteristics but also by which conservation tillage practice—mulch tillage, ridge tillage or no-tillage—is used (table 2.1). Second, results of field experiments on the effects of conservation tillage on yields are mixed. Several selected studies are reviewed here, and many more are cited.

The seven University of Illinois Agricultural Research and Demonstration Centers have evaluated crop yield response to different tillage systems under a wide variety of soil and climatic conditions (Siemans, 1997). The results have shown that crop yields vary due more to weather conditions during the growing season than the tillage system used. Corn and soybean yields are generally higher when the crops are rotated than when either crop is grown continuously. Comparative yields under a given tillage system vary with soil type (table 3.1). Corn and soybean yields generally decrease slightly as tillage is reduced on poorly drained soils. On these soils, however, ridge tillage often produced higher corn yields. On well to moderately-well drained, medium textured soils, yields with all tillage systems are similar for rotation corn and soybeans. With continuous corn, yields generally decrease as tillage is reduced. On excessively drained sandy soils, conservation tillage systems typically produce high yields.

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[21] The yield benefits of various types of conservation tillage vary; no-tillage will typically improve soil conditions much more rapidly than mulch or ridge tillage. Thus, the research comparing conventional tillage to conservation tillage has focused primarily on conventional tillage relative to no-tillage (Zero Tillage Farmers Association (1997).

[22] Rills and gullies on the surface and sand and soil deposits on bottomlands resulting from the heavy rains in 1993 forced farmers to till the soil more. Consequently, most of the benefits in terms of improved soil characteristics associated with conservation tillage were lost. The costs in the form of reduced net farm income for farmers who adopted conservation tillage were *ex post* greater than they had anticipated because the expected yield gain (if any were anticipated) from the use of conservation tillage could not be realized in the immediate future.

Epplin et al. (1994) conducted field experiments on wheat over a 10-year period (1977-1986) comparing different tillage systems: moldboard plow, chisel, disk, sweep, and no-tillage. Ridge tillage and mulch tillage were not considered. Wheat yields from the moldboard plow tillage systems were consistently greater and showed less variability than yields from the three intermediate tillage systems and no-tillage. The lowest yield was from the no-tillage practice. Moreover, yield was inversely related to the amount of crop residue cover on the field prior to planting. This is attributed to the root-borne and soil-borne pathogens, secondary toxins, and increased weed competition associated with the higher crop residue cover.

Young et al. (1994) found that, based on 6 years of field experiment results on wheat grown in eastern Washington, yields increased under conservation tillage relative to conventional moldboard plow tillage. Clark et al. (1994) found that wheat yields generally rose by about 10 percent when conservation tillage was combined with a wheat-fallow rotation.

As noted above, many other studies compared the yield effects of conservation tillage to the yields associated with conventional tillage practices. Most of the studies related to specific crops or cropping patterns and were limited in their geographic extent (see the *Crop Residue Management to Reduce Soil Erosion and Improve Soil Quality* series, compiled by the Agricultural Research Service, U.S. Department of Agriculture; Fox et al., 1991; and Roberts and Swinton, 1996). No clear consensus emerges from these studies concerning the effect of conservation tillage on yield relative to conventional tillage. The factors previously noted, including soil characteristics, climatic conditions, pest pressures, and cropping patterns, result in site-specific variation in yields that make it difficult to extract broad inferences.

One area did show some empirical consistency: yield under conservation tillage was generally riskier (more variable) than yield under conventional tillage. For example, Williams and Mikesell (1987), using the coefficient of variation as a measure of risk, found that for grain sorghum and soybean production in northeast Kansas, net returns under conservation tillage were considerably more risky than under conventional tillage. Setia (1987), using an expected-utility maximization framework, found that yields for both continuous corn and corn and soybeans in rotation are riskier under conservation tillage than conventional tillage.

Estimates of average yields (classified by tillage practice for nonirrigated corn, soybeans, winter wheat, spring wheat, and durum wheat for 1990-1995 and shown in table 3.2) from *Cropping Practices Survey* data (described in chapter 2) found no statistically significant difference in yields between conventional tillage and conservation tillage.[23] This result carries over when conservation tillage is disaggregated to mulch tillage, ridge tillage, and no-tillage, although the sample sizes for these subcategories are relatively small. Similar patterns were observed for irrigated crop production.

Another important result from the CPS data is the lack of a statistically significant difference between the variance in the yield for conservation tillage and for conventional tillage for corn and soybeans, although there was a difference for the winter and spring wheat where conventional tillage had a higher yield. For durum wheat, there was no statistically significant

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[23] The exception is spring wheat yields in 1992. Note that here and subsequently, tests of statistical significance are conducted at the 5-percent level. In drawing conclusions about statistical significance of the difference in the means of two samples, information on the sample size is needed. In the case of the *Cropping Practices Surveys*, the sample sizes are large enough so that the asymptotic limits of the relevant distributions can be used. Consequently, sample size information is not reported repeatedly. By way of example, however, the sample size for the full corn sample in 1995 was 2,745. For soybeans it was 2,085 and for winter wheat it was 1,936.

difference between the variance in the yield for conservation tillage and for conventional tillage for 1990 to 1992, but the variance was different for 1993 to 1995. Therefore, risk may be an important factor in the adoption of conservation tillage for wheat farmers, but apparently not for corn and soybean producers.

CPS data can also be used to conduct an analysis of variance to determine which factors have a statistically identifiable impact on yield.[24] Factors considered, in addition to tillage practice, include whether the cropland was designated highly erodible land (HEL), the number of hours devoted to tillage operations, the residue cover, the number of consecutive years which no-tillage has been used (on cropland using conservation tillage), and the previous crop planted. The single factor found to significantly affect yield is whether the cropland is designated as highly erodible (table 3.3). Yields were lower on HEL. Moreover, this significance was not dependent on the interaction between the HEL designation and any other variable. Thus, the difference in yield on HEL versus NONHEL land was not contingent on, for example, the tillage practice used or the previous crop grown or the use of conservation tillage in conjunction with the fact that the cropland is designated HEL. This holds for corn, soybeans, and the different types of wheat. Finally, the resulting statistical significance of just HEL does carry over to the years 1990-94.

In sum, for the crops for which survey data are available—corn, soybeans, and wheat (winter, spring, and durum)—there is no statistically identifiable association between tillage practice and yield for 1990 to 1995; yields are neither higher nor lower. There is, however, greater variability in the yields for winter wheat, spring wheat, and durum wheat that are conservation tilled.

Production Costs

For evaluating the profitability of conservation tillage relative to conventional tillage, the related costs of production are an important consideration. The different tillage practices may affect the cost of labor, fertilizers, pesticides, seed, and machinery. Grain handling and drying costs are affected if yields differ. Land cost is normally assumed not to vary with the tillage system.

Labor Use and Cost: A reduction in the intensity and number of tillage operations lowers costs for labor and machinery, especially if the machinery is used optimally (Siemans and Doster, 1992). Several studies estimate the savings in labor costs if conservation tillage is adopted. Weersink et al. (1992), found that corn-soybean farmers in southern Ontario realized significant savings in labor costs with no-tillage and ridge tillage compared with conventional tillage systems. The omission of preplant operations alone reduces labor requirements by up to 60 percent.

Dickey et al. (1992) calculated the typical labor requirements from machinery management data for various tillage systems in Nebraska (table 3.4). The moldboard plow system has the greatest labor requirement for tilling and planting corn and soybeans. Compared with the commonly used disk system, no-tillage, for example, saves about 20 minutes of labor per acre.

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[24] While the CPS data are not adequate to enable estimation of complete production functions, because data on many of the relevant factors impacting production were not collected, it is still possible to perform an analysis of variance to determine if, at an aggregate level, there is an identifiable relationship between yield and the tillage practice used. While an analysis of variance will permit a determination of the presence of a relationship, it will not allow a measurement of yield differentials associated with different tillage practices and attributable to these practices.

Cropping Practices Survey data also show that labor savings can be significant. The number of hours devoted to tillage operations are different for conservation tillage and conventional tillage, but the relative amount of time spent on tillage operations has not appreciably changed over time. In 1995, conventional tillage operations for corn took 0.38 hour per acre while conservation tillage required only 0.19 hour per acre. Soybeans and wheat took, respectively, 0.44 and 0.47 hour per acre for conventional tillage while conservation tillage operations on average took 0.20 and 0.22 hour per acre. All of these differences are statistically significant. Moreover, the relative amount of time devoted to the tillage operations for conservation tillage and conventional tillage has not changed between 1990 and 1995.

The benefit from conservation tillage of reduced labor needs is greater than just the labor cost savings per acre. There is the associated opportunity cost of the labor and time saved. That is, if less hired labor is needed, there will be direct savings. Saving the farmer's or other family members' labor may permit them to engage in off-farm activities. Lower labor requirements for tillage lead to additional returns from the expansion of existing enterprises or allow time for new activities to improve profitability for the whole farm operation.

Fertilizer Use and Cost: Assessing fertilizer needs to attain optimum yields depends on an accurate assessment of the soil's available nutrients in relation to the needs of the crop. This assessment will include site-specific factors such as soil characteristics, cropping patterns, and climatic conditions in addition to the tillage practice. Conservation tillage, however, requires improved fertilizer management (Halvorson, 1994 and Rehm, 1995). In some instances, increased application of specific nutrients may be necessary and specialized equipment required for proper fertilizer placement, thereby contributing to higher costs.

The results of field experiments indicate that an increase in the amount of crop residue cover on the soil surface tends to keep soils cooler, wetter, less aerated, and denser (Mengel et al., 1992). These characteristics and beneficial impacts from increased organic matter, improved moisture retention and permeability, and reduced nutrient losses from erosion are associated with conservation tillage and can affect the ability of crops to utilize nutrients. With higher levels of crop residue, proper timing and placement of nutrient applications are critical to enhance fertilizer efficiency to achieve optimal yield at lowest cost.

The overall effect of conservation tillage on fertilizer use is subject to some disagreement. Halvorsen (1994), suggests that fertilizer requirements and hence use are the same under conservation tillage and conventional tillage. Mengel et al. (1992) argue that it is not possible to determine *a priori* what will happen to fertilizer use because use is a function of many site-specific factors. Finally, Rehm (1995) suggests that fertilizer use will actually fall under conservation tillage because better fertilizer management practices (e.g., injection) will be used.

The *Cropping Practices Survey* can also be employed to examine the relationship between tillage and fertilizer use. For the most part, fertilizer use on conservation-tilled acreage was not statistically significantly different than fertilizer use on conventional-tilled acreage in 1995 (table 3.5). The exceptions are for potash used in corn, winter wheat, and spring wheat production. The reason for this is unknown. A similar pattern was observed for the years 1990-1994.

The CPS data, coupled with site-specific climatic information and fertilizer prices, allow for the estimation of demand functions for fertilizer. Demand functions are estimated for nitrogen, phosphate, and potash and are used to identify the factors, in addition to tillage

practice, that affect fertilizer use. While there is some variability across crops in the estimation results, use of both nitrogen and phosphate is about the same for conservation-tilled crops as for conventional-tilled crops. That is, fertilizer use, and hence costs, in the aggregate are the same for the different tillage practices although there will be site-specific/crop-specific/nontillage-related practice-specific variation.

Finally, the number of trips across a field to apply fertilizer did not vary between tillage systems. The average for corn for 1995 was 1.92 (0.03)[25] trips per field for conservation tillage and 1.90 (0.02) trips per field for conventional tillage. The average for soybeans, winter wheat, spring wheat, and durum wheat for conservation tillage is 0.31 (0.02), 1.32 (0.05), 1.31 (0.09), and 1.46 (0.11), respectively. The average for soybeans, winter wheat, spring wheat, and durum wheat for conventional tillage is 0.32 (0.02), 1.40 (0.03), 1.29 (0.05), and 1.40 (0.09), respectively. Consequently, there are no statistically significantly differences in labor costs or machinery operating and maintenance expenses associated with the application of fertilizer between conservation tillage and conventional tillage. The same results also hold for 1990-94.

Pesticide Use and Cost: Weed control problems vary among tillage systems because the nature of the weed population changes. Tillage prepares a seedbed not only for the crop but also for weed seeds (Monson and Wollenhaupt, 1995). Different weed species grow as tillage is reduced, requiring different control programs. Effective weed control with herbicides depends on spraying at the right stage of plant growth, plant stress, weather conditions, and so on. Weed growth and development, as well as appropriate management strategies, vary with location. A weed management program must be site specific and circumstance specific and will differ between conservation tillage and conventional tillage (Martin, 1992).

When a farmer uses conservation tillage, dormant weed seeds in the soil will no longer be transferred to the germination zone near the soil surface by tillage. Consequently, as annual weeds are controlled, the overall weed problem may decrease after a few years when fields are converted to conservation tillage and if effective weed control is practiced (Fawcett, 1987).

The *Cropping Practices Survey* can shed some light on the relative use of pesticides across different tillage systems. The survey results show that herbicide application rates for conservation tillage were slightly greater than for conventional tillage over the period 1990-1995 for corn, soybeans, and winter wheat (table 3.6). During this period, conservation-tilled acreage more than doubled, a pattern observed is consistent with the suggestion that in the first few years with a no-tillage system, farmers often use more herbicides. Other factors such as weather, soil type, tillage system experience, and endemic weed problems are potentially more important factors than the tillage system used in determining herbicide use. Moreover, the relative impacts of these factors vary from year to year.

Less insecticide is used for conservation tillage than for conventional tillage (Bull et al., 1993). From the CPS for 1995 for corn, for example, insecticide use on conservation tilled acreage was 0.61 (0.03)[26] pounds per acre versus 0.78 (0.04) pounds per acre for conventional-tilled acreage. For soybeans, insecticide use was 0.37 (0.05) and 0.50 (0.08) pounds per acre for

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[25] The standard error of the mean is in parentheses.

[26] As before, the standard error of the mean is in parentheses.

conservation-tilled and conventional-tilled acreage. The lower amounts of insecticide use on soybeans than on corn reflects a greater use of crop rotations.

Results from the *Cropping Practices Survey* suggest that the number of pesticide treatments is greater for corn, soybeans, and spring wheat grown under conservation tillage than under conventional tillage for some years between 1990 and 1995 (table 3.7). One possible reason for this is that pest problems occasionally are greater under conservation tillage. This is consistent with a recent survey of farmers in the Midwest, who rate the overall pest control problems to be 11 to 14 percent more severe on conservation-tilled soils than on conventional-tilled soils (Pike et al., 1997). Another possible reason is that split applications may be more prevalent with conservation tillage. The data are insufficient, however, to test this hypothesis.

An important caveat needs to be considered about the relationship between pesticide use and tillage practices. Pesticide use is measured by the number of pounds of active ingredients applied per acre. The active ingredient is the component of pesticide products that kills, repels, attracts, or controls the target pest. Aggregated active ingredient statistics, however, such as for the agricultural sector as a whole, for a crop, for a State, for a tillage system, or a class of pesticides often obscure significant differences among different pesticide products. For example, certain products are applied in pounds of active ingredient per acre while competing products are only applied at ounces per acre for the same crop and same target pest. While near term year-to-year comparisons can be useful in such instances, aggregate measures of pounds of active ingredient applied over time can be very misleading because of product changes, planted acreage shifts, regional shifts in acreage devoted to different crops, regulatory changes, and pest infestation cycles. For example, recommended application rates for herbicides have declined over time as new products have been introduced. As the analysis moves from a highly aggregated to a more disaggregated level such as to the individual active ingredient level, poundage comparisons over time, crop, or State are more meaningful. This issue is explored more fully in Barnard et al. (1997).

Few definitive statements can be made about pesticide use under conservation tillage versus conventional tillage. More herbicides are typically used during the first few years of conservation tillage. Insecticide use falls with conservation tillage. The existing cropping pattern, however, plays an important role in determining pesticide requirements because monoculture systems generally require greater pesticide use than crop rotation systems (Economic Research Service, 1997).

Seed Use and Cost: Seed cost in the context of conservation tillage has not been extensively studied. The question of whether the seeding rate or the type of seed used varies under conservation tillage relative to conventional tillage needs further study. Most field experiments (e.g., Iowa State University) maintain a constant seeding rate when comparing yields from conservation tillage to conventional tillage. A few studies casually considered seed costs. For example, it is has been recommended that when soybeans are drilled or planted in narrow rows, the seeding rate should be increased 10 to 20 percent compared with planting in rows 30 inches or wider (Siemans, 1997). The aggregate effects of these types of recommendations on the actual seeding rate, however, is an empirical issue that is a topic for future research (Aw-Hassan and Stoecker, 1990).

Results of the *Cropping Practices Survey* indicate that farmers did not vary the seeding rate by tillage practice in 1990-95 (table 3.8). Additionally, the variability in the seeding rate for each year and each crop is not statistically significantly different between conservation tillage and conventional tillage.

Empirical results for 1995 found no statistically significant differences between the seeding rate and the tillage practice used, whether the cropland was designated HEL, the number of hours devoted to tillage operations, the residue cover, the number of consecutive years which no-tillage has been used (on cropland using conservation tillage), and the previous crop planted (table 3.9). The statistical significance carries over to the years 1990-94, as well.

CPS data suggest that corn farmers in 1995 (the only year for which the requisite data are available), were no more likely to use herbicide-resistant hybrid seed or a Bt-enhanced variety of seed for insect control than those using conventional tillage. Only 6.3 (0.7)[27] percent of conventional tillage farmers used a herbicide-resistant seed in 1995, while just 7.6 percent (0.9) of conservation tillage farmers did. By comparison, 3.8 (0.6) percent of conventional tillage farmers used Bt-enhanced seed in 1995 while 2.4 (0.5) percent of conservation tillage farmers did. In both of these instances, differences are not statistically significant.

Machinery Use and Costs: Machinery-related costs typically range from $50 to $70 per acre per year (Siemans and Doster, 1992) and overshadow all other cost categories except land. As with the choice of other inputs, a farmer endeavors to perform the requisite field operations with the optimum or least cost machinery inventory. Because the optimum machinery inventory differs across tillage systems, direct comparison of machinery costs that can perform the desired field operations is difficult. As the size (width) of a machinery set increases, machinery productivity increases. But the annual machinery costs, fixed and variable, also increase with increasing machinery size, as illustrated by comparing the farm machinery operating costs for planting equipment (table 3.10). For conservation tillage, fewer implements and field operations are used. If conservation tillage is used on only part of the cropland, however, implements and tractors will need to be available for other portions, so cost comparisons will be more difficult. Thus, using a drill or narrow-row planter for soybeans is an option for most tillage systems. Owning a drill, however, for soybeans and a planter for corn often increases the machinery inventory and costs for a corn-soybean farm.

Additionally, a farmer who decides to convert from conventional tillage to conservation tillage exclusively must consider how to value his or her existing conventional tillage equipment. The equipment may not be fully depreciated, and farmers often have limited alternatives on how it might otherwise be used (Bates et al., 1979, John Deere and Co., 1980). A complete assessment of the production costs associated with conservation tillage versus conventional tillage must make some provision for the opportunity cost of the conventional tillage equipment. There are no data available, however, to permit a comparison of machinery costs between tillage systems.

Machinery operating costs may not be lower for conservation tillage (table 3.10). Lower fuel and maintenance costs associated with conservation tillage may be overshadowed by the higher cost of new conservation tillage implements. Lower fuel costs are a consequence of the fewer trips across a field with conservation tillage. Maintenance costs will be lower because the equipment will be used less (Hunt, 1984).

Cost Comparison for Different Tillage Systems

As the literature and the NASS/ERS CPS data show, it is difficult to draw definitive conclusions regarding the aggregate effects on farm profitability of conservation tillage. As shown, profits are a function of many site-specific factors including soil characteristics, local

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[27] The standard error is in parentheses.

climatic conditions, cropping patterns, and other attributes of the overall farming operations. The decision on which tillage system to adopt must be made at the individual farm level and be based on many site-specific factors. Even in this situation, there is some inherent uncertainty. For example, depending on the weed problem in a specific year, the herbicide cost can be relatively larger or smaller. This can make a seemingly good *ex ante* decision to adopt conservation tillage a poor one *ex post*. Along with machinery costs, herbicide use is the major input affected by a tillage system. As tillage is reduced, dependence on herbicides for weed control increases, but cost does not necessarily increase. In many field situations, as tillage is reduced, more expensive herbicide combinations and possibly a contact herbicide may be required to achieve adequate weed control. In many cases, herbicide cost is the same for conservation tillage and conventional tillage. Depending on herbicide cost, the production costs of conservation tillage can be greater than, equal to, or less than those for conventional tillage (table 3.11).

The cost comparisons from table 3.11 are based on the assumption that the farmer is acquiring new equipment—either for conservation tillage or for conventional tillage. Changing tillage practices from conventional tillage to conservation tillage, however, requires careful consideration. Machinery purchases may be justified if soil erosion is a primary concern or if equipment purchase is part of a normal replacement schedule. Account must be taken of any remaining value of conventional tillage equipment in assessing the relative costs of conservation tillage versus conventional tillage.

Environmental Benefits and Costs of Conservation Tillage

Background

A relatively small portion of cropland—that with high erosion rates—is responsible for a large proportion of total soil eroded in the United States (Magleby et al., 1995). Moreover, this cropland with high erosion rates is geographically concentrated. The soil erosion problem associated with agricultural production is not uniformly spread across the United States. Figure 3.1 portrays the geographic distribution of sheet and rill erosion in the United States while figure 3.2 portrays the distribution of wind erosion. In general, a soil erosion rate in excess of 5 tons per acre leads to a reduction in soil productivity (Alt et al., 1989). The greater the erosion rate, the greater the reduction in long-term agricultural productivity (the onsite cost of soil erosion) and impairment of water resources (the offsite cost of soil erosion).

The most widespread offsite erosion-related problem is impairment of water resource use (National Research Council, 1993). The Environmental Protection Agency has identified siltation associated with erosion in rivers and lakes as the second leading cause of water quality impairment, and agricultural production is identified as the leading cause of water quality impairment (U.S. Environmental Protection Agency, 1995).

Three related causes of water use impairment are sedimentation, eutrophication, and pesticide contamination. When soil particles and agricultural chemicals wash off a field, they may be carried in runoff until discharged into a water body or stream. Not all agricultural constituents transported from a field reach water systems, but a significant portion does, especially dissolved chemicals and the more chemically active, finer soil particles. Once agricultural pollutants enter a water system, they lower water quality and can impose economic losses on water users. These offsite impacts can be substantial. The offsite impacts of erosion are potentially greater than the onsite productivity effects in the aggregate (Foster and Dabney, 1995). Therefore, society may have a larger incentive for reducing erosion than farmers have.

If the runoff reaches the water body or stream, soil particles can be suspended in the water, or settle out as sediment, depending on the velocity of the waterflow and the size of the soil particles. In each case, water use can be affected.

Suspended soil particles affect the biologic nature of water systems by reducing the transmission of sunlight, raising surface water temperatures, and affecting the respiration and digestion of aquatic life. The effects on aquatic life, and the reduction in aesthetic quality of recreation sites, can reduce the value of water for recreation uses. Suspended soil particles impose costs on water treatment facilities, which must filter out the particles. Suspended soil particles can also damage moving parts in pumps and turbines.

Even when soil particles settle on the bottom of a river or lake, they can cause serious problems for aquatic life by covering food sources, hiding places, and nesting sites. Sedimentation can clog navigation and water conveyance systems like roadside ditches, reduce reservoir capacity, and damage recreation sites. In streambeds, sedimentation can lead to increased frequency and severity of flooding by reducing channel capacity.

The nutrients and pesticides attached to soil particles, or dissolved in runoff, affect water quality in ways that can affect the suitability of water for many uses (Baker, 1987). The most far-reaching impact is eutrophication, abundant growth of algae and rooted vegetation caused by excessive nutrient runoff. As algae dies and decays, it uses oxygen from the surrounding water, lowering the dissolved oxygen levels and altering the size and composition of commercial and recreational sport fisheries. Rooted plants can become a nuisance around marinas and shorelines. Floating algae blooms can restrict light penetration to surface waters and can affect the health, safety, and enjoyment of people using water for recreation. Floating algae can clog intake pipes and filtration systems, increasing the cost of water treatment.

Pesticides, which include herbicides, insecticides, and fungicides, create a broad array of impacts. Most notable are effects on aquatic life. Very high concentrations will kill organisms outright. Lower concentrations, more commonly observed, can produce a variety of sublethal effects such as to lower resistance of fish, which makes them susceptible to other stresses (Glotfelty, 1987). Herbicides can hinder photosynthesis in aquatic plants (Schepers, 1987). Pesticides can damage commercial and sport fisheries and make fish dangerous to eat (Herndon, 1987).

Several studies evaluated the improvements in water quality associated with the use of conservation tillage. Richards and Baker (1998) report on the effort to reduce the eutrophication in Lake Erie that began in the early 1970's. A monitoring station was set up at Bowling Green, Ohio, on the Maumee River, which feeds into Lake Erie. Agriculture is the dominant land use in the Maumee River basin, where the major crops are corn, soybeans, and wheat. Between 1975 and 1995, implementation of no-tillage and reduced tillage (table 2.1) increased from less than 5 percent to more than 50 percent of planted acreage. Fertilizer (nitrogen and phosphorus) application rates also changed over the period so it is not possible to quantify precisely the contribution of conservation tillage to the water quality improvements. Nevertheless, water quality changes over the study period were evaluated by conducting trend studies of concentrations and loads. The adoption of conservation tillage in conjunction with the reduced fertilizer application rates led to a reduction in total phosphorus loadings of 24 percent, a reduction in suspended sediments of 19 percent, and a reduction in total Kjeldahl nitrogen of 10 percent.

Fawcett et al. (1994)[28] surveyed the effects of various best management practices, including conservation tillage, on pesticide runoff into surface water and leaching into groundwater. They concluded that no-tillage systems provide a reduction in runoff losses for active pesticide ingredients studied. Average[29] herbicide runoff in no-tillage systems, for example, was 30 percent of the conventional tillage runoff. Additionally, ridge tillage and chisel plow practices are less effective than no-tillage in reducing soil erosion on HEL but are relatively good production practices on less erodible fields. For the various conservation tillage practices relative to conventional tillage, herbicide runoff was 70 percent less for no-tillage while it was 42 percent less for ridge tillage. With regard to leaching, however, conservation tillage does not fare as well. Increases in infiltration accompanying the use of conservation tillage may result in a greater threat to groundwater from pesticides or nitrate. Preferential flow of water through macropores, which may be more prevalent with no-tillage, can allow water and dissolved solutes or suspended sediment to bypass upper layers of soil. This may transfer pesticides to shallow groundwater or to depths in the soil where biological degradation is slower. It is important, however, to keep this in perspective. Even though there is an increase in the potential leaching risks of certain pesticides associated with conservation tillage, the relative concentrations of pesticides found in surface water are typically greater than concentrations in groundwater.

Wind erosion produces offsite impacts that can be as dramatic as the Dust Bowl of the 1930's, but it has not, received the attention given to the more widespread water erosion impacts. Damage can include higher maintenance of buildings and landscaping, pitting of automobile finishes and glass, greater wear on machinery parts, increased soiling and deterioration of retail inventories, costs of removing blown sand and dust from roads and ditches, and increased respiratory and eye disorders. Offsite damages from wind erosion depend on the extent and location of population centers relative to prevailing winds and wind erosion sources (Piper and Lee, 1989). Consequently, damage estimates for one area cannot readily be extrapolated to other areas, nor can the impact of wind erosion from cropland or other agricultural land be differentiated from wind erosion originating on nonagricultural land.

Offsite impacts of both sheet and rill erosion and wind erosion may be subject to threshold effects (Zison et al., 1977). A reduction in erosion may not produce proportional improvements in water or air quality unless they are quite large in relation to total loads. In economic terms, the costs of erosion control practices that result in only small reductions in erosion may produce few, if any, offsite benefits.

A third and somewhat ancillary erosion-related problem deals with wildlife. Monoculture production and field consolidation have diminished habit diversity in areas where agriculture once contributed to diversity (Strohbehn, 1986). Soil conservation practices frequently enhance wildlife habitat. Field borders, windbreaks, hedgerows, streambank protection, and wildlife habitat management can increase habitat diversity. Practices aimed at wildlife protection, however, often divert land from row crop production, thereby creating opportunity costs.

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[28] There is also a companion piece that repeats the conclusions of this study. See Ciba Geigy Corporation (1992).

[29] The conditions under which the field experiments are performed and from which averages are computed are critical. Basta et al. (1997) explore this issue.

Measuring the Offsite Benefits of Soil Erosion Reduction: To quantify the benefits of reduced soil erosion, from both water and wind, it is necessary first to determine the reduction in soil erosion associated with conservation tillage relative to conventional tillage and then calculate the social benefits associated with this reduction. An approach often used to measure soil losses by sheet and rill erosion is the universal soil loss equation (USLE) (Wischmeier and Smith, 1978).[30] Wind-related soil losses are measured by the wind erosion equation (WEQ) (Skidmore and Woodruff, 1980 and Smith and English, 1982). These two equations describe the relationships currently used by the Natural Resources Conservation Service of the U.S. Department of Agriculture to calculate the soil loss on cropland in the United States. They are an integral part of the conservation practice standards used to determine conservation compliance (Natural Resources Conservation Service, 1997). They will be used here to assess the reduction in soil erosion associated with an increase in the use of conservation tillage. The appendix provides a technical definition of each type of soil loss. It also provides a technical definition of highly erodible land.[31]

Before using the USLE and WEQ to assess the benefits of increasing the use of conservation tillage, a discussion of the data used in the analysis is needed.[32]

National Resources Inventory: Every 5 years since 1977, the Natural Resources Conservation Service (NRCS) has conducted a statistically representative National Resources Inventory (NRI) of land cover and use, soil erosion, prime farmland, and other natural resource statistics on non-Federal, rural land. Based on actual field observations by NRCS technicians, the NRI provides a profile of the Nation's conservation practices and future program needs. The most recent complete inventory was conducted in 1992 (Soil Conservation Service, 1992).[33] The data consist of information on 236 variables from collected at approximately 1 million sites, with most cropland points representing 1,500-2,600 acres. Information on all of the components of the USLE and WEQ is reported.

The NRI data show that 94 million acres of Highly Erodible Land (HEL) were not conservation-tilled in 1992, of which 24.5 million acres had USLE erosion rates above the soil loss tolerance level T and 22.2 million acres had wind erosion rates above T.[34] Of this HEL,

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[30] A more recent development in terms of measuring soil loss potential is the work of the Water Erosion Prediction Project (WEPP). Because it is still under development and not completely operational, it will not be used here. The interested reader is referred to Becker (1997).

[31] An analysis of the structure of these relationships can be found in Wittmuss (1987) and Uri and Hyberg (1990).

[32] The latest version of USLE is the Revised Universal Soil Loss Equation (RUSLE). It is not used here because it was not used in developing the data for the 1992 Natural Resources Inventory (see below). RUSLE is an improvement over USLE in that it incorporates more data (from different crops and cropping patterns, different locations, for forest and rangeland erosion), it corrects errors in the USLE analysis and fills gaps in the original data, and it possesses increased flexibility which allows modeling a greater variety of systems and alternatives (Yoder and Lown, 1995, and Renard et al., 1996). For the analysis presented here, the results would be substantially the same using either measure.

[33] Annual updates to the NRI were prepared for selected subsamples in 1995, 1996, and 1997. These updates, however, are not comprehensive.

[34] A technical definition of T is provided in the appendix.

about 15 million acres had either or both USLE or wind erosion rates above 2*T, which implies that continued production would not be sustainable. In addition, the data show that, only about 10 percent (20 million acres) of NONHEL cropland had either USLE or wind erosion rates or both above the soil loss tolerance level T.

Implications of Reducing Soil Erosion by Converting All Cropland to Conservation Tillage: An evaluation was made of the implications of reducing soil erosion by converting all cropland to conservation tillage based on the 1992 NRI data. Table 3.12 defines for each crop or land use the assumption made about the adoption of conservation tillage. The cropland uses recorded in the NRI were divided into three groups, each of which required a different set of procedures. The first group of crops used for this analysis is those for which conservation tillage is either not practical or it is technologically infeasible. This group includes intensively tilled crops like potatoes, vegetables, and hay crops for which tillage is already very limited. For these crops, tillage type and erosion rates are assumed to remain unchanged (tables 3.13-3.16). This group constitutes 43 million acres of HEL and 53 million acres of NONHEL cropland.

The second cropland use category in this analysis is the group of major field crops for which high rates of conservation tillage adoption already exist. For these crops, it is assumed that acres currently not conservation-tilled could switch. For sheet and rill erosion, it is assumed that for each crop a switch to conservation tillage would change the USLE residue management factor (C) to that where the crop is conservation-tilled.[35] Since sufficient information is not available for recalculating the wind erosion equation, it is assumed that for each crop a switch to conservation tillage will result in the same wind erosion rate as crops currently conservation tilled (labeled "CONTIL" in tables 3.13 and 3.15; erosion rates for each crop are listed in tables 3.14 and 3.16). This group constitutes 48 million acres of HEL and 166 million acres of NONHEL cropland.

The third group of crops is mainly fruit, nuts, and Conservation Reserve Program (CRP) acreage where it is assumed that a grass cover will be maintained resulting in the same erosion rates as a hay crop ("HAYCOV" in tables 3.13 and 3.15; erosion rates are shown in tables 3.14 and 3.16). This group is relatively small—3.6 million acres of HEL and 13.5 million acres of NONHEL.

The results of the analysis show that the total erosion reduction due to the assumed adoption of conservation tillage is 326 million tons per year (tables 3.13 and 3.15). For HEL, the reduction in sheet and rill soil erosion rates from 4.1 to 3.2 tons per acre per year and the reduction in wind-related erosion rates from 4.6 to 4.0 tons per acre per year result in an average savings of 1.3 tons per acre per year on 94 million acres. For NONHEL, the reduction in sheet and rill soil erosion rates from 2.3 to 1.8 tons per acre per year and the reduction in wind-related soil erosion rates from 1.4 to 1.0 tons per acre per year result in a savings of 0.9 ton per acre per year on 233 million acres. Erosion rates vary geographically and by crop. Some of this variability is an artifact of the assumptions, and some is a function of the erosion potential of the cropland. Thus, for example, corn and soybeans, which are grown in regions where highly erodible land is relatively common, have the potential for realizing substantial

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[35] Note that data on the residue management factor in the NRI are not disaggregated by tillage subcategories. Thus, the value of C is reported only for general tillage categories such as conventional tillage and conservation tillage and not, e.g., conventional tillage with moldboard plow and no-tillage.

reductions in the erosion rate, while peanuts and tobacco have no potential for contributing to a reduction in the erosion rate (table 3.14).

Social (Offsite) Benefits of Converting Highly Erodible Cropland to Conservation Tillage

The change in erosion rates is one method of assessing the benefits of switching to conservation tillage. The benefit measure, however, is in physical units (tons per acre per year). Such a measure does nothing to quantify the offsite social benefits of a reduction in soil erosion. This requires estimates of the offsite damages associated with erosion.

Ribaudo (1989) developed comprehensive estimates of the offsite damages associated with sheet and rill erosion.[36] The approach has been applied in a number of settings (e.g., Magleby et al., 1995, and Ribaudo et al., 1990). The estimates take into account damage to water uses such as recreation, water storage facilities, commercial fishing, navigation, water storage, drinking water supplies, industrial water supplies, and irrigation. The estimates, compiled from an eclectic assortment of studies, are used here with the assumption that any reduction in offsite damages translates into a comparable increase in social benefits.

Huszar and Piper (1986) have derived estimates of the offsite damages due to wind erosion. Considerable uncertainty, in quantifying the damages due to wind erosion is a function of the poor understanding of households' response to blowing soil and how damages vary with population density. Absent any better alternative, however, these estimates will be used with the assumption that any reduction in offsite damages will lead to a comparable increase in social benefits.

Combining the estimates of sheet and rill and wind erosion damages with data on the amount of HEL that is not treated with an acceptable conservation system and with the previously presented results on changes in the erosion rate if HEL is converted to conservation tillage, it is possible to estimate the social benefits of bringing the remaining HEL under conservation tillage. This, of course, presumes that the untreated HEL is switched to conservation tillage. Note that only untreated HEL is used in the analysis because it has been the focus of conservation compliance. In 1996, there were 22.4 million HEL acres in the United States that were not adequately treated using some type of conservation management system or technical practice. Additional social benefits will result if conventional-tilled NONHEL is switched to conservation tillage but the per acre benefits would be lower. A comparable number of acres of NONHEL switched, however, will result in a smaller social benefit because the erosion rate on NONHEL is lower than it is for HEL (tables 3.13 and 3.15).

Data on the number of untreated HEL acres for 1996 are taken from the Conservation Technology Information Center (1996). Table 3.17 presents the social benefits by State associated with a reduction in sheet and rill erosion, and table 3.18 presents social benefits for a reduction in wind erosion. Wind erosion estimates are calculated only for States in four regions: the Mountain, Northern Plains, Pacific, and Southern Plains. The soil erosion estimates derived are applicable only to States in these regions (Piper, 1990).

The best (most likely to be realized) estimate for the social benefits of a reduction in sheet and rill soil erosion is $32 million annually. For wind erosion, the estimate is $17.6 million

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[36] Ribaudo and Hellerstein (1992) discuss the methodological issues associated with estimating the water quality benefits associated with reduced sheet and rill erosion.

annually. These estimates are likely overstated because it is not feasible to convert all HEL to conservation tillage. Some soils must be tilled regardless of whether they are HEL or not.[37] This can involve conventional tillage practices or mulch tillage or ridge tillage.

The Realized Social (Offsite) Benefits of Conservation Tillage in 1996

Using the same approach as that used for computing the social benefits of converting the remaining highly erodible cropland to conservation tillage, it is possible to estimate the change in soil erosion and the social benefits associated with the use of conservation tillage in 1996. By assuming that all conservation tilled acres in 1996 had been conventionally tilled and comparing the associated erosion rates to the erosion rates for the same acres conservation tilled, estimates of both the physical reduction in soil loss and the social benefits can be made. Data on the number of acres that were conservation tilled in 1996 was taken from the Conservation Technology Information Center (1996). An estimate of the number of conservation-tilled acres that are highly erodible is based on the percent of total cropland acres in a State that are highly erodible. The estimated changes in sheet and rill and wind erosion rates associated with a change in tillage practice are those given in tables 3.13 and 3.15. Estimates of offsite damages associated with sheet and rill erosion are taken from Ribaudo (1989) while estimates of offsite wind erosion damage comes from Huszar and Piper (1986).

Table 3.19 presents State-level estimates of the reduction in soil erosion associated with using conservation tillage instead of conventional tillage. The table also presents the social benefits associated with a reduction in sheet and rill erosion. Table 3.20 presents erosion reduction and social benefits associated with wind erosion. As before, wind erosion estimates are calculated only for States in four regions, the Mountain, Northern Plains, Pacific, and Southern Plains, since the soil erosion estimates derived are applicable only to States in these regions.

Sheet and rill erosion was reduced by about 66 million tons in 1996 in the United States because of conservation tillage (table 3.19). The best estimate of social benefits of the reduction is $103 million. For wind erosion, the estimate of the reduction in soil erosion is 31.5 million tons (table 3.20). The best estimate of the social benefits associated with the reduction is $45 million.

The Realized Social (Offsite) Benefits of Conservation Compliance

A significant change in U.S. conservation policy came in the Food Security Act of 1985 in the form of conservation compliance.[38] While meeting the conservation provisions remains voluntary, a farmer who wants to receive certain agricultural program payments and whose cropland is designated as HEL has no choice but to implement an acceptable conservation plan. Requirements for conservation compliance were applied to HEL previously cultivated in any year between 1981 and 1985. Conservation compliance required farmers producing crops on HEL to implement and maintain an approved soil-conservation system by 1995.

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[37] A number of specific types of soil benefit from conventional tillage, including soils that are generally wet in the spring and that can benefit from the creation of elevated seed beds in the fall, soil where the crops produce insufficient residue to control wind erosion so that tillage is required to bring up clods, soils near residential areas on which manure is disposed (this avoids the objectionable odor), soils where residues on the surface cool the soil or carry over diseases or insects that significantly decrease crop production, soils on which high-value crops with small seeds need precise seeding depths and cannot tolerate clumps of residues, soils that become very compacted when the moisture content declines, and soils on which weeds or trees cannot be killed by herbicides (Kemper, 1995).

[38] Conservation compliance is discussed more extensively in the next chapter. Conservation tillage is a significant factor in the conservation management systems and technical practices used for compliance.

In 1996, the Natural Resources Conservation Service (NRCS) conducted a status review of conservation compliance through 1995 to determine its effect on aggregate soil loss (Natural Resources Conservation Service, 1996). The estimated changes are categorized by crop residue cover and reported in physical units (table 3.21).[39] Using the same approach as that used for computing the social benefits of converting the remaining highly erodible cropland to conservation tillage, it is possible to provide a nominal estimate of the social benefits associated with conservation compliance through 1995.

As a result of conservation compliance, it is estimated that sheet and rill erosion on average has been reduced by about 61 percent on HEL in the United States. This translates into a best estimate of realized social benefits of the reduction of $579 million (table 3.21).

The Impact of Conservation Tillage on Wildlife and Wildlife Habitat

The use of a particular tillage system has several effects on wildlife. The amount of crop residue cover on the soil surface differs depending on the tillage practice used. Other factors include the availability of waste grain and other wildlife foods, the frequency and extent of disturbance to nesting, and the direct and indirect effects of pesticide use (Best, 1995). Wildlife species familiar to agricultural land include the ring-necked pheasant, bobwhite quail, cottontail rabbit, meadowlark, white-tailed deer, killdeer, and barn owl. These species use cropland and grassland for nesting, feeding, and escaping predators, although it must be recognized that farming operations other than tillage take place on the acreage.

Conservation tillage use benefits wildlife mainly by leaving crop residue on the soil surface during spring and summer which may be used as cover (Brady, 1985). In a study conducted in the early 1980's, there was a greater abundance of invertebrates, birds, and mammals in conservation-tilled than in conventionally tilled corn fields in southern Illinois (Warburton and Klimstra, 1984). A greater diversity and density of birds nested in conservation-tilled fields than in conventionally tilled fields in Iowa, and nest success was comparable to idle areas, such as fence rows and waterways (Basore et al., 1986 and Castrale, 1985).[40] Additionally, increased residue cover tends to diversify rather than increase populations of small mammals (Young and Clark, 1983 and Young, 1984). The relatively high residue associated with conservation tillage provides more and ostensibly better conditions for feeding. Tillage also influences the availability of insects (Martin et al., 1951). For example, it has been estimated that the amount of time a quail chick needs to satisfy its daily insect requirement is 4.2 hours on a no-tillage soybean field, 11.1 hours on a no-tillage corn field, 22.2 hours on a conventional-tilled soybean field, and 25.1 hours on a conventional-tilled corn field (Conservation Technology Information Center, 1997). If weeds are controlled by herbicides, there is minimal disturbance to residue-nesting wildlife after planting. If weeds are controlled by cultivation as in the case of ridge tillage, there is a good chance of physical disturbance to residue-nesting wildlife.

Several factors influence how well conservation tillage will improve wildlife habitat, including the specific crop grown. Legumes (soybeans) are highly desirable because they are best able to support native grassland species (Ribaudo et al., 1990). Another factor is the quality of the

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[39] The changes in the rate of soil erosion are computed using the Universal Soil Loss Equation.

[40] A few species such as the horned lark and the killdeer are adversely affected by tillage practices that leave more residue on the soil. These species prefer open habitats (Best, 1995).

cover established, in terms of height and density, which is related to the chosen mix of vegetation.

Wildlife recreationists are the primary beneficiaries from increases in wildlife populations associated with an increase in the use of conservation tillage. Hunters enjoy higher numbers and quality of species, while fishermen will encounter greater numbers of fish. Increased wildlife habitat also provides more opportunities for enjoying nonconsumptive activities such as bird watching, photography, and hiking.

Quantification of these sorts of benefits is difficult because there are no well-defined markets for the activities[41] and hence no available transactions prices. Some surveys, which endeavored to indicate the number of people engaged in various wildlife-associated recreational activities and the economic value they attach to the activities, inferred the benefits of greater wildlife populations resulting from conservation tillage. One such survey, *1991 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation* conducted by the Fish and Wildlife Service (U.S. Fish and Wildlife Service, 1993), consisted of a telephone interview and follow-up of 129,500 households nationwide of those who had fished, hunted, or engaged in a nonconsumptive wildlife-related activity in 1990. Among the values collected on the survey was the net economic value of a specific activity where net economic value is defined as a participant's willingness to pay above what he or she actually spent to participate. The benefit to society is defined as the sum of the willingness to pay across all individuals. Estimates of the net economic value per person per year for trout fishing range from highs of $965, $584, and $485 in California, New York, and Arizona, respectively, to lows of $235 for Maine and $236 for Pennsylvania. The mean value across all States was $374 (Waddington et al., 1994). For deer hunting, the net economic value per person per year ranges from $768, $744, $705, and $701 for Maryland, New Hampshire, Alabama, and Rhode Island, respectively, to lows of $168 for Iowa, $252 for Idaho, and $254 for Montana. The average over all the States was $490. Estimates of the net economic value per person per year for wildlife watching range from $763 in Indiana to $106 in North Dakota. Other States with high annual values include Alaska at $655 and Arkansas at $558. Iowa, West Virginia, and Maryland with $136, $171, and $182, respectively have relatively low net economic values per year. The average net economic value across all States was $278 (Waddington et al., 1994).

The Reduction in Carbon Emissions Associated with Conservation Tillage

An increase in conservation tillage has two identifiable effects with regard to carbon emissions. First, no-tillage results in an increase in carbon retention in the soil because less organic matter is lost to oxidation from mixing of the soil, and soil temperatures tend to be lower, which slows oxidation from mixing of the soil. The lower soil temperature slows decomposition (Tate, 1987). Second, conservation tillage is more energy efficient than conventional tillage, requiring fewer machinery operations and hence less energy. Thus, carbon emissions are reduced because less fossil fuel (gasoline and diesel fuel) is used.

The amount and kind of crop residues have an effect on organic carbon levels in the soil (Rasmussen et al., 1980). Conservation tillage may increase the amount of soil organic carbon in the soil by providing an environment where fungal decomposition is greater than bacterial

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[41] For example, there is no estimate of the bird watching demand for wildlife in a neoclassical microeconomic setting.

decomposition. Fungal decomposition results in more recalcitrant decomposition products than bacterial decomposition (Holland and Coleman, 1987).

Historically, conventional tillage has resulted in losses of soil carbon (Hunt et al., 1996 and Zobeck et al., 1995). While this long-run effect of conventional tillage is clear, there are a number of unresolved questions with respect to modifying the processes that promote carbon loss from the soil. One is the relative importance of the different processes affected by tillage such as soil disturbance and the way tillage impacts changing carbon inputs and losses. An answer to this question is necessary before an accurate assessment can be made of the long-run effect of different tillage systems on the carbon level in the soil (Barker et al., 1996).

While conventional tillage in the long run does alter soil structure and increase the loss of soil carbon, the magnitude of these effects is a function of the intensity of tillage, the frequency of tillage, and the quantity and quality of fertilizer and organic residue returned to the soil (Rasmussen and Collins, 1991).

Conservation tillage has a potential for converting many soils from sources of atmospheric carbon to carbon sinks. The extent of the potential carbon sequestration, however, is highly variable (Donigian et al., 1994). This variability is a function of the crop grown, the cropping pattern, the type of soil, and climatic conditions. Given this variability, and given the fact that a substantial number of objective studies of carbon sequestration associated with conservation tillage for various crops, cropping patterns, soil types, and climatic conditions are not yet available,[42] it is difficult to assess the aggregate social benefit of reduced carbon emissions associated with increased use of conservation tillage.[43] Compounding the assessment problem is the fact that rates of carbon emissions from the soil are significantly correlated with temperature and precipitation and have a pronounced seasonal pattern. Hence, estimates of any aggregate effects must be based of studies incorporating climatic conditions and seasonal changes. The available data are simply not adequate to make a credible aggregate estimate even though some have tried (e.g., Kern and Johnson, 1993).[44] More studies of the sort by Gilley et al. (1997) that assess the relative carbon content of different tillage practices on comparable soils are needed.

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[42] Some studies do exist. Reicosky et al. (1995) and Reicosky (1995) have surveys of these.

[43] One study that does focus on tillage methods is Reicosky and Lindstrom (1993). It indicates major gaseous loss of carbon immediately following tillage. The study reports the results of the effects of fall tillage methods on carbon dioxide flux from a Hamerly clay loam in the northern Corn Belt comparing moldboard plow, moldboard plow plus disk harrow, disk harrow only, and chisel plow with an area not tilled. Measurements immediately after tillage and intermittently for 19 days showed that differences in carbon dioxide losses were related to soil fracturing that facilitated the movement of carbon dioxide out of and oxygen into the soil. The moldboard plow treatment buried nearly all of the residue and left the soil in a rough, loose, and open condition and resulted in the maximum carbon dioxide loss. The amounts released during those 19 days can be compared with the equivalent carbon loss in tops and roots of the previous wheat crop (Reicosky et al., 1995). With plowing only, the carbon dioxide loss was greater than the equivalent carbon input from the previous crop. The carbon released as carbon dioxide during the 19 days following moldboard plow, moldboard plow plus disk harrow, chisel plow, and not tilled treatments would account for 134, 70, 58, 54, and 27 percent, respectively, of the carbon in the current year's crop residue.

[44] Kern and Johnson use a number of disparate studies to estimate the change in soil organic carbon. The studies relied upon come from a number of different countries using different production technologies. Additionally, very different soil types and crops are aggregated together. They find that converting about 70 percent of cropland from conventional tillage to conservation tillage will offset 0.7 percent to 1.1 percent of the U.S. fossil fuel emissions in the United States between 1990 and 2020.

The second way that conservation tillage reduces carbon emissions is through reduced consumption of gasoline and diesel fuel. Even with slightly more herbicide use in the first few years of some systems, conservation tillage is more energy efficient than conventional tillage (Frye, 1995). Quantifying the reduction in carbon emissions, however, due to reduced energy use is elusive. Farm equipment in U.S. agriculture consists of a mix of gasoline and diesel fuel tractors (Uri and Day, 1992). A precise profile of this mix of gasoline and diesel fuel using equipment, however, is not available. Since carbon emissions vary by type of fossil fuel and size of equipment, it is not possible to provide a quantitative estimate of any reduction in carbon emissions from a change in fossil fuel consumption associated with conservation tillage.

Conclusion

A review of relevant studies and results from the *Cropping Practices Survey* points to a lack of conclusive evidence that conservation tillage leads to higher yields (at least not in the short run). Moreover, the costs of inputs, including labor, fertilizer, pesticides, seeds, and machinery, are so dependent on site-specific factors that general inferences about production costs are not possible.

The evidence does lead to the following conclusions:

- If conservation tillage is used continuously, soil quality will improve, thus increasing the long-term productivity of the land.

- The use of conservation tillage does result in less of an adverse impact on the environment from agricultural production than conventional tillage by reducing surface water runoff and wind erosion.

- Wildlife habitat will be enhanced to some extent with the adoption of conservation tillage.

- The benefits to be gained from carbon sequestration will depend on the soil remaining undisturbed.

- Further expansion of conservation tillage on highly erodible land will unquestionably result in an increase in social benefits, but the expected gains will be modest.

Several government policies can be used to encourage the adoption of conservation tillage if that is deemed desirable after weighing all the evidence. This is the subject of the following chapter.

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Figure 3.1

Sheet and rill erosion: Average cropland soil erosion rates

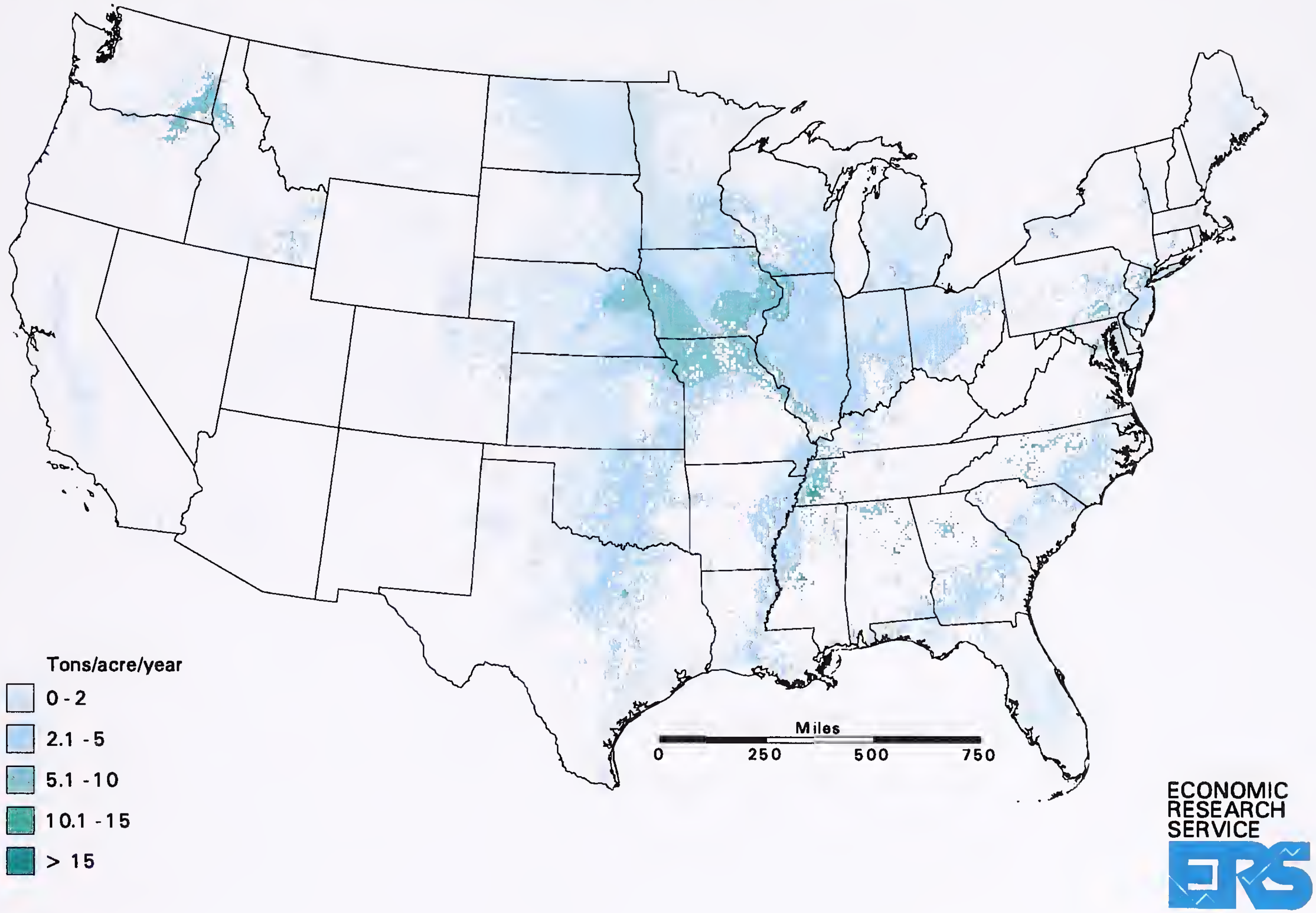

Figure 3.2
Wind erosion: Average cropland soil erosion rates

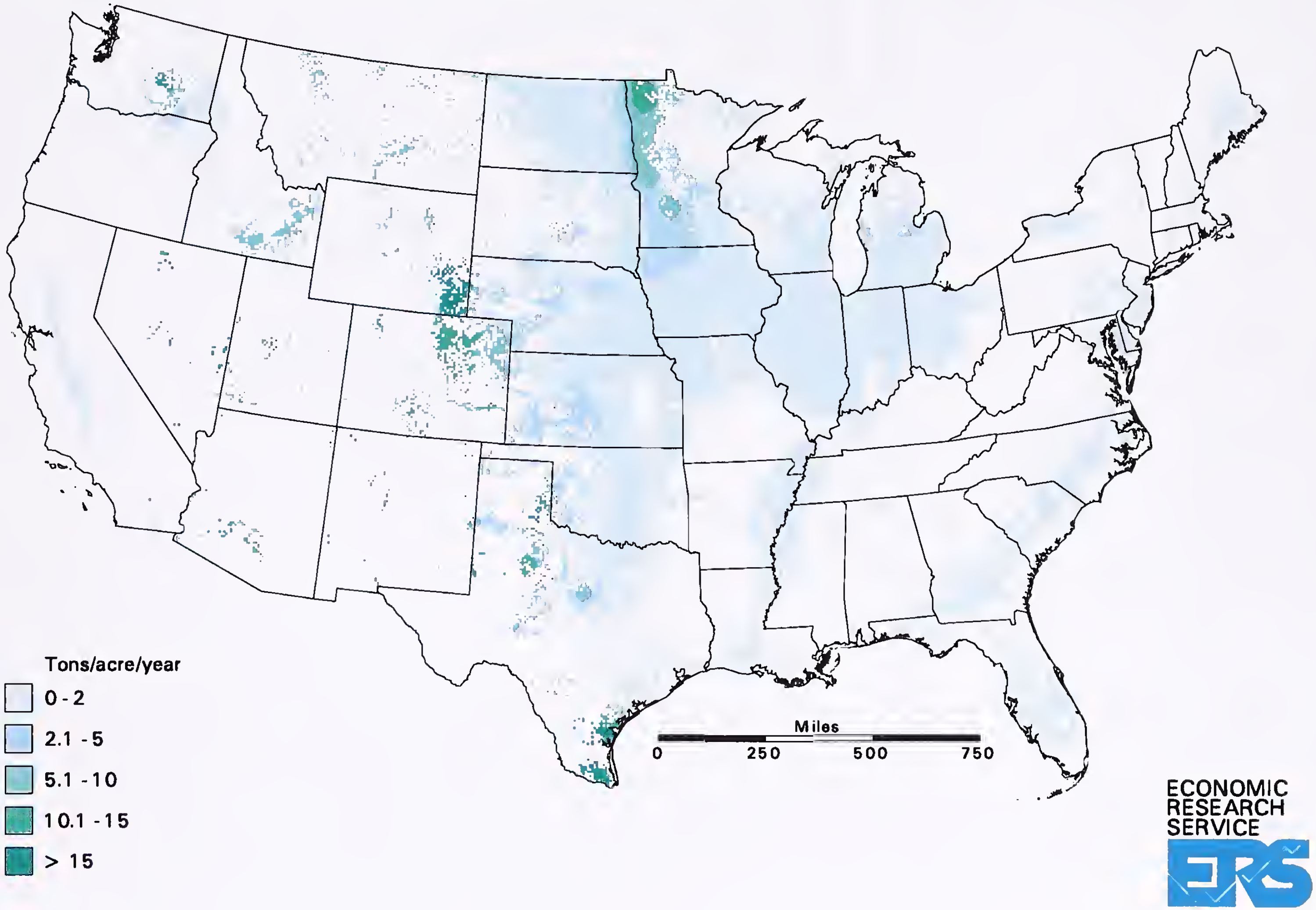

Table 3.1—Corn and soybean yields in Illinois by tillage system and soil type

Tillage system	Soil type, years of experiment						
	Thorp silt loam, 1991-1995	Alford silt loam, 1989-1993	Flanagan silt loam, 1990-1994	Cisne silt loam, 1990-1994	Downs-Fayette silt loam, 1990-1994	Tama silt loam,[1] 1990-1994	Tama silt loam,[2] 1988-1994
	5-year average corn yields (bu/acre)						
Moldboard plow	*	155	163	*	172	165	140
Chisel plow	164	156	153	138	170	155	137
Disk	170	160	160	138	171	165	135
No-tillage	164	153	150	133	167	159	136
	5-year average soybean yields (bu/acre)						
Moldboard plow	42	41	54	28	44	54	*
Chisel plow	*	44	50	29	47	55	*
Disk	43	46	52	*	46	53	*
No-tillage	40	42	54	32	45	53	*

* denotes system not included in experiment.

1 Corn-soybean rotation.
2 Continuous corn.

Source: Siemans (1997).

Table 3.2—Average yields by tillage practice

Commodity/year	Conventional tillage	Conservation tillage
	Bushels/acre	
Corn		
1990	122.1 (1.20)[1]	122.6 (1.39)
1991	114.5 (1.17)	117.1 (1.91)
1992	143.1 (1.33)	146.7 (1.58)
1993	106.5 (0.80)	104.7 (0.87)
1994	146.1 (0.71)	144.9 (0.86)
1995	118.0 (0.95)	116.1 (1.11)
Soybeans		
1990	38.1 (0.25)	37.7 (0.41)
1991	40.2 (0.60)	39.6 (0.42)
1992	41.7 (0.34)	43.1 (0.39)
1993	37.6 (0.28)	39.2 (0.29)
1994	45.0 (0.26)	45.4 (0.28)
1995	39.9 (0.40)	39.7 (0.36)
Winter wheat		
1990	41.1 (0.51)	43.4 (1.04)
1991	41.5 (0.58)	39.1 (0.97)
1992	37.5 (0.49)	38.4 (1.05)
1993	42.4 (0.64)	42.7 (1.04)
1994	41.2 (0.54)	42.5 (1.12)
1995	44.4 (0.76)	44.4 (1.18)
Spring wheat		
1990	42.1 (1.06)	39.9 (1.87)
1991	35.7 (0.70)	31.8 (1.98)
1992	46.7 (1.14)	38.7 (2.35)
1993	37.6 (1.21)	32.6 (2.23)
1994	34.1 (0.75)	31.9 (1.33)
1995	33.3 (0.84)	32.5 (1.35)
Durum wheat		
1990	40.0 (1.39)	38.7 (1.42)
1991	35.1 (0.91)	31.6 (0.94)
1992	40.7 (1.27)	36.8 (1.35)
1993	35.0 (2.35)	36.0 (5.19)
1994	33.6 (0.84)	33.7 (1.28)
1995	31.2 (0.92)	29.4 (1.35)

[1] The values in parentheses are standard errors.

Source: U.S. Department of Agriculture, ERS/NASS, *Cropping Practices Survey*, 1990-1995

Table 3.3—Analysis of variance of yields based on the Cropping Practices Survey, 1995

Commodity	HEL[1]	CONTIL[2]	HEL*CONTIL[3]
		ANOVA sum of squares	
Corn	53545.6 (**)	683.5 (ns)	3838.3 (ns)
Soybeans	7549.5 (**)	641.9 (ns)	1529.9 (ns)
Winter Wheat	12497.5 (**)	278.1 (ns)	0.0 (ns)
Spring Wheat	8601.4 (*)	213.1 (ns)	2717.6 (ns)
Durum Wheat	233.5 (ns)	418.2 (ns)	89.9 (ns)

Note: The values in the table are the ANOVA sum of squares for the respective variables. The characters in parentheses indicate whether the sum of squares is not statistically significant (ns), whether it is statistically significant at the 5-percent level or better (*), or whether it is statistically significant at the 1-percent level or better (**).

[1] HEL indicates whether the land was designated as highly erodible land.
[2] CONTIL indicates whether conservation tillage was used.
[3] HEL*CONTIL is the interaction term.

Table 3.4—Labor requirements for various tillage systems in Nebraska

Operation	Moldboard plow	Chisel plow	Disk	Ridge tillage	No-tillage
			Hours per acre		
Chop Stalks	0.38	0.21	na[1]	0.17	na
Fertilize, knife	0.13	0.13	0.13	0.13	0.13
Disk	0.16	0.16	0.16	na	na
Plant	0.21	0.21	0.21	0.25	0.25
Cultivate	0.18	0.18	0.18	0.36	na
Spray	na	na	na	na	0.11
Total	1.22	0.89	0.84	0.91	0.49

[1] na denotes not applicable.

Source: Dickey et al. (1992)

Table 3.5—Average fertilizer use by tillage practice, 1995

Commodity/nutrient	Conventional tillage	Conservation tillage
	Pounds per acre	
Corn		
Nitrogen	130.8 (1.92)[1]	136.5 (3.21)
Phosphate	47.9 (1.22)	43.9 (2.30)
Potash	59.3 (1.74)	49.6 (1.79)
Soybeans		
Nitrogen	4.5 (0.74)	4.5 (0.64)
Phosphate	13.2 (1.36)	10.4 (1.00)
Potash	22.5 (1.95)	22.5 (1.87)
Winter Wheat		
Nitrogen	61.7 (1.61)	55.6 (2.84)
Phosphate	20.9 (0.87)	23.5 (1.84)
Potash	9.3 (0.87)	17.0 (2.08)
Spring Wheat		
Nitrogen	58.0 (2.91)	47.4 (4.93)
Phosphate	26.2 (1.42)	29.9 (1.52)
Potash	6.2 (0.91)	1.4 (0.62)
Durum Wheat		
Nitrogen	59.9 (4.55)	65.1 (5.88)
Phosphate	17.6 (1.55)	19.0 (2.09)
Potash	1.3 (0.49)	1.5 (1.49)

[1] Values in parentheses are the standard errors.

Source: U.S. Department of Agriculture, ERS/NASS, *Cropping Practices Survey*, 1995

Table 3.6—Average herbicide use by tillage practice

Commodity/year	Conventional tillage	Conservation tillage
	Pounds of active ingredient applied per acre	
Corn		
1990	3.38 (1.01)[1]	3.27 (1.06)
1991	2.98 (0.71)	3.25 (0.59)
1992	3.03 (0.66)	3.32 (0.68)
1993	2.99 (0.53)	3.42 (0.48)
1994	2.77 (0.51)	3.33 (0.44)
1995	2.72 (0.89)	3.31 (0.63)
Soybeans		
1990	1.28 (0.96)	2.09 (1.21)
1991	1.22 (0.68)	1.51 (0.51)
1992	1.14 (0.50)	1.31 (0.49)
1993	1.06 (0.65)	1.38 (0.48)
1994	1.10 (0.51)	1.35 (0.30)
1995	1.02 (1.20)	1.35 (0.68)
Winter wheat		
1990	0.26 (0.47)	0.54 (0.51)
1991	0.29 (0.44)	0.71 (0.41)
1992	0.30 (0.47)	0.32 (0.44)
1993	0.28 (0.30)	0.47 (0.50)
1994	0.31 (0.43)	0.43 (0.50)
1995	0.25 (0.37)	0.36 (0.50)

[1]Values in parentheses are standard errors.

Source: U.S. Department of Agriculture, ERS/NASS, *Cropping Practices Survey*, 1990-1995

Table 3.7—Average number of pesticide treatments by tillage practice

Commodity/year	Conventional tillage	Conservation tillage
	Number of treatments	
Corn		
1990	1.63 (0.02)[1]	1.69 (0.03)
1991	1.69 (0.02)	1.78 (0.04)
1992	1.71 (0.02)	1.82 (0.03)
1993	1.67 (0.02)	1.77 (0.02)
1994	1.72 (0.02)	1.82 (0.02)
1995	1.79 (0.03)	1.93 (0.03)
Soybeans		
1990	1.49 (0.02)	1.51 (0.03)
1991	1.54 (0.03)	1.63 (0.04)
1992	1.57 (0.03)	1.63 (0.03)
1993	1.47 (0.02)	1.62 (0.02)
1994	1.67 (0.02)	1.77 (0.02)
1995	1.64 (0.03)	1.87 (0.04)
Winter wheat		
1990	0.41 (0.02)	0.55 (0.05)
1991	0.39 (0.02)	0.36 (0.05)
1992	0.39 (0.02)	0.32 (0.04)
1993	0.50 (0.02)	0.49 (0.05)
1994	0.53 (0.02)	0.55 (0.05)
1995	0.76 (0.02)	0.75 (0.05)
Spring wheat		
1990	1.26 (0.05)	1.42 (0.14)
1991	1.17 (0.04)	1.20 (0.07)
1992	1.14 (0.05)	1.03 (0.07)
1993	1.19 (0.06)	1.12 (0.08)
1994	1.24 (0.07)	1.18 (0.05)
1995	1.07 (0.02)	1.17 (0.03)
Durum wheat		
1990	1.48 (0.09)	1.52 (0.12)
1991	1.38 (0.09)	1.47 (0.10)
1992	1.45 (0.11)	1.27 (0.09)
1993	1.67 (0.27)	1.56 (0.33)
1994	1.38 (0.07)	1.42 (0.10)
1995	1.41 (0.09)	1.50 (0.14)

[1] The values in parentheses are standard errors.

Source: U.S. Department of Agriculture, ERS/NASS, *Cropping Practices Survey*, 1995

Table 3.8—Average seeding rate by tillage practice

Commodity/year	Conventional tillage	Conservation tillage
	Kernels per acre	
Corn		
1990	24645 (84.847)[1]	24613 (153.35)
1991	25010 (102.62)	24884 (172.47)
1992	25521 (120.61)	25542 (161.02)
1993	25727 (69.084)	25716 (90.012)
1994	26002 (67.602)	25809 (91.643)
1995	26550 (109.88)	26319 (128.87)
	Pounds per acre	
Soybeans		
1990	62.5 (0.42)	67.9 (1.05)
1991	62.4 (0.52)	64.9 (0.95)
1992	55.2 (0.87)	53.2 (1.16)
1993	66.8 (1.50)	72.9 (1.51)
1994	66.1 (1.46)	72.4 (1.65)
1995	55.1 (3.52)	62.8 (3.64)
Winter wheat		
1990	74.1 (0.97)	69.2 (2.16)
1991	76.5 (0.98)	74.6 (2.93)
1992	75.3 (0.84)	69.2 (2.04)
1993	73.0 (0.86)	71.8 (2.40)
1994	71.9 (0.79)	74.8 (2.57)
1995	61.1 (1.13)	59.3 (2.32)
Spring wheat		
1990	92.3 (1.34)	88.3 (2.45)
1991	89.0 (1.61)	84.4 (1.80)
1992	93.5 (1.52)	87.7 (1.72)
1993	89.3 (1.33)	94.0 (3.71)
1994	96.4 (1.84)	92.1 (2.22)
1995	94.2 (2.68)	92.1 (5.11)
Durum wheat		
1990	97.1 (1.81)	97.8 (1.91)
1991	100.1 (1.67)	103.5 (2.21)
1992	93.8 (1.83)	97.6 (1.86)
1993	99.3 (1.33)	104.0 (8.71)
1994	99.7 (1.88)	103.3 (1.41)
1995	98.5 (3.24)	96.3 (2.93)

[1] Values in parentheses are standard errors.

Source: U.S. Department of Agriculture, ERS/NASS, *Cropping Practices Survey*, 1990-1995

Table 3.9—Analysis of variance of the seeding rate based on the Cropping Practices Survey, 1995

Commodity	HEL[1]	CONTIL[2]	HEL*CONTIL[3]
		ANOVA sum of squares	
Corn	27023.8 (ns)	2548.8 (ns)	5277.9 (ns)
Soybeans	15425.9 (ns)	514.6 (ns)	6092.2 (ns)
Winter wheat	1501.1 (ns)	50.6 (ns)	0.0 (ns)
Spring wheat	17304.1 (ns)	2147.0 (ns)	1660.5 (ns)
Durum wheat	838.3 (ns)	286.3 (ns)	36.8 (ns)

Note: The values in the table are the ANOVA sum of squares for the respective variables. The characters in parentheses indicate whether the sum of squares is not statistically significant (ns), whether it is statistically significant at the 5-percent level or better (*), or whether it is statistically significant at the 1-percent level or better (**).

[1] HEL indicates whether the land was designated as highly erodible land.
[2] CONTIL indicates whether conservation tillage was used.
[3] HEL*CONTIL is the interaction term.

Table 3.10—Planting equipment operating costs

Machine	Tractor size	Net cost of a new implement	Estimated work performed	Total cost per hour	Total cost per acre[1]	Operating expense per acre	Diesel fuel
	HP	*Dollars*	*Acres per hour*		*Dollars*		*Gallons per acre*
Row crop planter 8-30[2]	75	20,290	9.33	60.77	6.51	1.10	0.43
Row crop planter 12-30[2]	105	32,637	14.00	85.45	6.10	1.02	0.40
Minimum tillage planter 8-30	105	27,640	8.48	76.51	9.02	1.54	0.66
Minimum tillage planter 12-30	160	46,599	12.73	98.11	7.71	1.80	0.67
No-tillage drill 30 ft	200	52,423	12.73	122.59	9.63	2.02	0.83

[1] Includes tractor, machinery, and labor costs.
[2] Used on conventional tillage systems.

Source: Doane's Agricultural Report (1997)

Table 3.11—Machinery, labor, and herbicide costs for corn and soybeans, by tillage system on a 1,000-acre corn-soybean farm in central Illinois

	Tillage system[1]					
After soybeans After corn	Chisel MB plow	Disk Chisel	Disk Disk	No-tillage Chisel	No-tillage No-tillage	Ridge tillage Ridge tillage
	$/acre					
Corn						
Machinery costs	55	50	48	44	37	44
Labor[2]	8	7	7	7	5	7
Herbicides	10-15	10-15	10-15	15-25	15-25	5-25
Total	73-78	67-72	65-70	66-76	57-67	56-76
Expense (E) or savings (S),[3]		1-11(S)	3-13(S)	3(E)-12(S)	6-12(S)	3(E)-22(S)
Soybeans						
Machinery costs	55	50	48	44	37	44
Labor	8	7	7	7	5	7
Herbicides	14-28	14-28	14-28	14-28	25-40	7-40
Total	77-91	71-85	69-83	65-79	67-82	58-91
Expense (E) or savings (S),[3]		8(E)-20(S)	6(E)-22(S)	2(E)-26(S)	5(E)-24(S)	14(E)-33(S)

[1] Both corn and soybeans planted in rows. The least cost machinery set is such that both corn and soybeans are planted in and harvested in a timely manner so opportunity costs are negligible.
[2] Labor cost is assumed to be $8.50 per hour.
[3] Compared to chisel/moldboard (MB) plow system.

Source: Siemans and Doster (1992)

Table 3.12—Crop management assumptions for changing to conservation tillage

Land use	No change[1]	Switch to conservation tillage[2]	Cover management switch[3]
Fruit			X
Nuts			X
Vineyard			X
Bush fruit			X
Berries			X
Horticulture - other			X
Corn		X	
Sorghum		X	
Soybeans		X	
Cotton		X	
Peanuts	X		
Tobacco	X		
Sugar beets	X		
Potatoes	X		
Vegetables - other	X		
Row crops - other	X		
Sunflowers		X	
Wheat		X	
Oats		X	
Rice		X	
Barley		X	
Close - other		X	
Hay/grass	X		
Hay/legume	X		
Hay/legume/grass	X		
Summer fallow	X		
Not planted			X
CRP[4]	X		

[1] Erosion of these crops is already equal to that of conservation tillage or else the crop is very unlikely to switch to conservation tillage.
[2] It is assumed these crops switch to conservation tillage. The contribution to soil loss is assumed to be like other planted acreage in the area that has already switched.
[3] The crop cover is assumed to be similar to a hay crop and contribute to soil loss in a way similar to hay.
[4] Conservation Reserve Program acreage.

Source: Natural Resources Conservation Service (1994)

Table 3.13—Erosion and crop change for conservation tillage adoption on HEL, State-level results

State	ACRES	USLE92	USLENEW	WEQ92	WEQNEW	HAYCOV	CONTIL	NOCHANGE
	1000's	*T/a/yr*[1]				*1,000 acres*		
Alabama	1,288.3	6.6	4.5	0.0	0.0	160.6	532.7	595.0
Arkansas	270.1	4.9	3.3	0.0	0.0	29.8	103.3	137.0
Arizona	488.2	0.5	0.1	14.6	0.4	166.3	257.9	64.0
California	879.7	4.1	3.4	3.2	0.6	284.9	250.7	344.1
Colorado	5,138.1	2.1	2.0	10.9	8.5	109.4	2,799.3	2,229.4
Connecticut	23.0	4.0	2.1	0.0	0.0	3.6	3.9	15.5
Delaware	1.3	12.5	10.3	0.0	0.0	0.0	0.7	0.6
Florida	167.5	3.4	2.6	0.0	0.0	71.3	46.4	49.8
Georgia	702.5	9.6	7.1	0.0	0.0	147.1	272.1	283.3
Iowa	3,980.5	6.7	6.3	0.5	0.4	38.7	1,592.9	2,348.9
Idaho	2,427.4	3.2	2.8	5.1	3.8	78.4	1,059.9	1,289.1
Illinois	3,098.8	10.2	7.6	0.0	0.0	36.6	2,245.6	816.6
Indiana	786.5	8.4	6.0	0.1	0.1	58.7	479.3	248.5
Kansas	7,265.0	2.3	2.0	2.8	2.5	8.6	4,753.9	2,502.5
Kentucky	1,985.4	5.0	3.8	0.0	0.0	62.8	362.3	1,560.3
Louisiana	138.3	3.0	2.9	0.0	0.0	16.0	69.0	53.3
Massachusetts	22.4	0.6	0.5	0.0	0.0	4.6	1.4	16.4
Maryland	229.9	9.1	6.3	0.0	0.0	10.8	110.4	108.7
Maine	22.9	1.3	1.3	0.0	0.0	2.0	3.6	17.3
Michigan	472.9	5.8	4.1	1.1	0.8	50.6	198.9	223.4
Minnesota	2,005.5	6.4	4.7	3.2	1.8	29.4	1,081.8	894.3
Missouri	3,965.6	7.6	5.7	0.0	0.0	104.8	1,391.6	2.469.2
Mississippi	1130.6	9.6	8.2	0.0	0.0	146.8	396.7	587.1
Montana	10,041.3	1.7	1.2	6.5	3.0	4.4	6,430.1	3,606.8
North Carolina	689.8	12.7	11.0	0.0	0.0	115.4	277.0	297.4
North Dakota	6,001.8	1.8	1.3	3.1	0.9	98.7	3,308.0	2,595.1
Nebraska	4,519.6	4.0	3.7	2.6	2.7	105.1	2,751.6	1,662.9
New Hampshire	26.0	1.2	1.1	0.0	0.0	0.0	1.1	24.9
New Jersey	54.8	6.3	4.3	0.1	0.1	10.7	15.4	28.7
New Mexico	1,968.8	0.6	0.6	12.1	8.3	217.9	802.9	948.0
Nevada	365.8	0.1	0.0	25.8	5.0	130.7	0.9	234.2
New York	1,581.2	4.1	3.2	0.0	0.0	81.9	363.7	1,135.6
Ohio	1,494.4	7.0	5.0	0.0	0.0	78.7	574.0	841.7
Oklahoma	2,532.2	2.6	2.2	3.0	3.0	14.2	1,508.6	1,009.4
Oregon	1,039.3	2.6	1.9	2.3	1.0	65.2	313.5	660.6
Pennsylvania	3,520.0	4.4	4.3	0.0	0.0	190.5	1,392.2	1,937.3
Rhode Island	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Carolina	327.6	5.4	3.3	0.0	0.0	66.5	128.1	133.0
South Dakota	2,420.9	2.7	2.3	3.4	2.3	14.9	1,080.2	1,325.8
Tennessee	2,552.5	8.6	6.1	0.0	0.0	143.6	1,110.3	1,298.6
Texas	9,149.3	2.1	1.9	15.2	15.2	314.8	5,680.2	3,154.3
Utah	551.6	0.8	1.0	7.3	5.6	82.7	97.0	371.9
Virginia	1,091.0	6.5	5.4	0.0	0.0	73.3	279.3	738.4
Vermont	121.3	2.5	1.6	0.0	0.0	0.0	12.7	108.6
Washington	3,069.6	6.0	4.4	6.6	3.9	147.4	2,014.2	908.0
Wisconsin	2,723.6	5.9	5.1	0.0	0.0	58.2	1,137.4	1,528.0
West Virginia	462.7	2.4	1.8	0.0	0.0	18.4	33.5	410.8
Wyoming	1,264.2	1.1	1.1	14.1	13.8	7.7	465.5	791.0
United States	94,059.7	4.1	3.2	4.6	4.0	3662.7	47,791.7	42,605.3

[1] T/a/yr denotes tons per acre per year.

ACRES is the HEL acreage that was not conservation-tilled in 1992.
USLE92 is the value of the Universal Soil Loss Equation for 1992.
USLENEW is the Universal Soil Loss Equation value after changing to conservation tillage.
WEQ92 is the value of the Wind Erosion Equation for 1992.
WEQNEW is the value of the Wind Erosion Equation after changing to conservation tillage.
HAYCOV is acreage that was planted in any crop similar to hay cover.
NOCHANGE is acreage changing to a mix of crops with conversion to conservation tillage.
CONTIL is acreage changing to conservation tillage but the same crop is planted.
Source: Natural Resources Conservation Service (1994)

Table 3.14—Erosion and crop change for conservation tillage adoption on HEL, totals by crop

Land use	ACRES	USLE92	USLENEW	WEQ92	WEQNEW
	1000's		*T/a/yr*[1]		
Fruit	638.9	1.7	1.7	0.7	1.4
Nuts	136.2	1.4	0.5	2.6	1.8
Vineyard	102.0	2.6	1.6	0.3	1.8
Bush fruit	0.9	0.5	0.5	0.0	0.0
Berries	18.9	2.9	1.9	0.0	0.0
Horticulture - other	143.4	6.4	1.5	1.3	0.4
Corn	10,444.6	10.4	8.2	2.8	2.0
Sorghum	3,647.2	3.6	3.1	13.0	10.1
Soybeans	4,566.8	14.1	10.8	0.7	0.5
Cotton	3,339.5	6.0	5.3	22.1	22.1
Peanuts	411.1	8.5	8.5	9.3	9.3
Tobacco	366.5	17.1	17.1	0.0	0.0
Sugar beets	269.1	1.7	1.7	12.4	12.4
Potatoes	393.6	2.1	2.1	15.3	15.3
Vegetables - other	613.1	6.5	6.5	9.1	9.1
Row crops - other	505.7	2.4	2.4	8.4	8.4
Sunflowers	113.8	1.4	0.6	6.6	2.3
Wheat	14,434.0	3.7	2.9	7.4	4.5
Oats	1134.8	5.5	4.9	2.5	1.0
Rice	20.8	3.8	0.0	0.0	0.0
Barley	1,509.4	5.1	4.0	6.9	3.2
Close - other	1,032.8	4.7	3.6	5.0	2.4
Hay/grass	7,752.7	1.1	1.1	0.2	0.2
Hay/legume	4,898.2	1.3	1.3	2.4	2.4
Hay/legume/grass	7,597.1	2.0	2.0	0.2	0.2
Summer fallow	7,548.0	3.4	2.7	9.0	5.5
Not planted	2,622.4	4.4	1.2	10.4	1.3
CRP	19,796.2	0.8	0.8	1.1	1.1
United States	94,059.7	4.1	3.2	4.6	4.0

[1] T/a/yr denotes tons per acre per year.

ACRES is the HEL acreage that was not conservation-tilled in 1992.
USLE92 is the value of the Universal Soil Loss Equation for 1992.
USLENEW is the Universal Soil Loss Equation value after changing to conservation tillage.
WEQ92 is the value of the Wind Erosion Equation for 1992.
WEQNEW is the value of the Wind Erosion Equation after changing to conservation tillage.

Source: Natural Resources Conservation Service (1994)

Table 3.15—Erosion and crop change for conservation tillage adoption on NONHEL, State-level results

State	ACRES	USLE92	USLENEW	WEQ92	WEQNEW	HAYCOV	CONTIL	NOCHANGE
	1000's	*T/a/yr*[1]				*1,000 acres*		
Alabama	2,325.6	4.7	3.6	0.0	0.0	359.0	1,326.1	640.5
Arkansas	7,090.9	3.2	2.9	0.0	0.0	202.7	6,482.8	405.4
Arizona	670.9	0.6	0.4	12.5	2.7	240.0	351.4	79.5
California	7,981.7	0.4	0.3	0.4	0.2	2,441.0	3,576.9	1,963.8
Colorado	2,513.5	1.5	1.3	5.0	3.1	69.1	1,252.6	1,191.8
Connecticut	205.5	3.3	1.2	0.0	0.0	44.0	56.6	104.9
Delaware	158.7	2.6	2.1	0.9	1.3	7.6	128.1	23.0
Florida	2,768.5	1.0	0.7	0.0	0.0	1,310.4	852.0	606.1
Georgia	4,544.1	3.9	3.5	0.0	0.0	754.7	2,309.8	1,479.6
Iowa	7,695.8	2.6	2.2	1.8	1.1	163.5	6,246.0	1,286.3
Idaho	2,226.4	1.5	1.3	2.5	1.9	110.0	827.3	1,289.1
Illinois	14,386.7	3.0	2.2	0.0	0.0	66.9	13,554.6	765.2
Indiana	8,868.4	2.9	1.9	0.4	0.4	322.9	7,637.5	908.0
Kansas	14,339.0	2.2	1.9	1.3	1.2	15.5	12,276.2	2,047.3
Kentucky	1,762.1	3.2	2.1	0.0	0.0	28.2	946.3	787.6
Louisiana	5,800.7	3.5	3.3	0.0	0.0	933.4	4,004.6	862.7
Massachusetts	247.0	1.3	1.4	0.0	0.0	42.3	38.4	166.3
Maryland	505.8	3.6	3.1	0.1	0.1	32.2	342.4	131.2
Maine	421.9	1.1	1.1	0.0	0.0	21.9	34.6	365.4
Michigan	7,149.2	1.5	1.2	2.2	1.4	620.0	4,088.9	2,440.3
Minnesota	18,945.5	1.5	1.1	5.6	3.9	446.3	14,192.1	4,307.1
Missouri	8,639.0	3.3	2.3	0.0	0.0	256.6	6,668.0	1,714.4
Mississippi	4,772.0	3.9	3.7	0.0	0.0	558.7	3,738.8	474.5
Montana	4,095.2	1.1	0.9	3.1	1.5	7.3	2,127.8	1,960.1
North Carolina	4,921.8	4.1	3.0	0.0	0.0	484.8	3,338.3	1,098.7
North Dakota	20,561.0	1.1	0.8	1.4	0.6	504.7	16,746.7	3,309.6
Nebraska	11,314.5	2.9	2.6	1.0	0.9	319.4	9,170.1	1,825.0
New Hampshire	114.6	0.8	0.9	0.0	0.0	7.7	14.1	92.8
New Jersey	499.8	4.2	3.4	0.0	0.0	111.0	237.4	151.4
New Mexico	57.0	0.3	0.3	3.9	3.1	7.3	12.8	36.9
Nevada	396.5	0.0	0.0	0.7	0.1	27.3	4.9	364.3
New York	3,990.3	1.8	1.7	0.0	0.0	269.3	1,305.8	2,415.2
Ohio	7,640.6	2.6	1.5	0.1	0.1	230.5	6,068.2	1,341.9
Oklahoma	4,467.3	3.2	2.6	0.8	0.8	84.6	3,787.2	595.5
Oregon	2,321.3	2.0	1.5	0.5	0.6	155.0	1,168.9	997.4
Pennsylvania	1,342.3	2.8	2.6	0.0	0.0	57.4	568.0	716.9
Rhode Island	24.6	2.5	0.9	0.0	0.0	7.2	3.3	14.1
South Carolina	2,754.3	2.8	2.4	0.0	0.0	237.7	2,013.4	503.2
South Dakota	13,217.5	1.7	1.4	1.9	1.4	152.4	9,890.7	3,174.4
Tennessee	2,037.9	3.9	2.5	0.0	0.0	77.2	1,430.0	530.7
Texas	13,014.8	2.6	2.4	3.6	2.4	1,126.8	9,721.7	2,166.3
Utah	1,375.0	1.0	1.0	2.4	1.6	68.5	473.3	833.2
Virginia	1,460.5	2.8	2.5	0.2	0.2	69.1	711.1	680.3
Vermont	503.5	1.0	1.0	0.0	0.0	5.8	94.2	403.5
Washington	4,104.0	2.1	1.7	2.8	1.5	271.0	2,603.8	1,229.2
Wisconsin	7,409.6	1.9	1.7	0.2	0.3	122.2	3,823.3	3,464.1
West Virginia	387.2	1.0	0.6	0.0	0.0	17.9	64.0	305.3
Wyoming	1,064.6	0.3	0.2	1.9	1.9	12.8	144.3	907.5
United States	233,094.6	2.3	1.8	1.4	1.0	1,3481.8	166,455.3	53,157.5

[1] T/a/yr denotes tons per acre per year.

ACRES is the NONHEL acreage that was not conservation-tilled in 1992.
USLE92 is the value of the universal soil loss equation for 1992.
USLENEW is the value of the universal soil loss equation after changing to conservation tillage.
WEQ92 is the value of the wind erosion equation for 1992.
WEQNEW is the value of the wind erosion equation after changing to conservation tillage.
HAYCOV is acreage that was planted in any crop similar to hay cover.
NOCHANGE is acreage changing to a mix of crops with conversion to conservation tillage.
CONTIL is acreage changing to conservation tillage but the same crop is planted.
Source: Natural Resource Conservation Service (1994)

Table 3.16—Erosion and crop change for conservation tillage adoption on NONHEL, totals by crop

Land use	ACRES	USLE92	USLENEW	WEQ92	WEQNEW
	1000's	*T/a/yr*[1]			
Fruit	2,195.9	0.6	0.2	0.1	0.1
Nuts	1,027.9	0.4	0.2	0.0	0.2
Vineyard	517.8	0.7	0.2	1.0	0.2
Bush fruit	55.3	0.7	0.2	0.2	0.2
Berries	167.3	1.0	0.3	0.1	0.0
Horticulture-other	429.8	2.0	0.3	0.4	0.1
Corn	48,040.8	3.0	2.4	1.4	0.9
Sorghum	7,105.1	3.2	3.0	2.7	1.8
Soybeans	39,109.4	3.4	2.6	1.1	0.7
Cotton	9,547.4	4.1	4.0	2.5	1.0
Peanuts	1,547.6	5.5	5.5	1.0	1.0
Tobacco	863.9	5.8	5.8	0.0	0.0
Sugar beets	958.9	1.0	1.0	8.0	8.0
Potatoes	750.8	2.1	2.1	3.4	3.4
Vegetables-other	2,231.3	2.6	2.6	1.6	1.6
Row crops-other	1,965.3	2.0	2.0	2.3	2.3
Sunflowers	1,575.7	1.3	1.0	3.3	2.3
Wheat	38,070.8	2.1	1.7	2.2	1.6
Oats	2,916.3	2.2	2.0	1.4	1.0
Rice	3,626.0	2.1	2.0	0.0	0.0
Barley	4,175.8	1.3	1.0	2.8	1.9
Close - other	3,232.7	1.6	1.5	1.3	0.6
Hay/grass	10,690.3	0.4	0.4	0.1	0.1
Hay/legume	8,222.7	0.6	0.6	0.6	0.6
Hay/legume/grass	11,627.7	0.7	0.7	0.2	0.2
Summer fallow	9,055.3	2.1	1.8	3.1	2.0
Not planted	9,087.8	1.7	0.4	1.5	0.3
CRP	14,243.8	0.4	0.4	0.3	0.3
United States	233,094.6	2.3	1.8	1.4	1.0

[1] T/a/yr denotes tons per acre per year.

ACRES is the HEL acreage that was not conservation-tilled in 1992.
USLE92 is the value of the Universal Soil Loss Equation for 1992.
USLENEW is the Universal Soil Loss Equation value after changing to conservation tillage.
WEQ92 is the value of the Wind Erosion Equation for 1992.
WEQNEW is the value of the Wind Erosion Equation after changing to conservation tillage.

Source: Natural Resources Conservation Service (1994)

Table 3.17—Annual benefits of conservation tillage associated with reduced sheet and rill erosion on untreated HEL

State	Range			Best[1]
		1,000 dollars		
Alabama	965	-	2,235	1,583
Arkansas	26	-	143	43
Arizona	0	-	0	0
California	0	-	0	0
Colorado	157	-	427	280
Connecticut	67	-	224	112
Delaware	4	-	14	7
Florida	18	-	41	29
Georgia	128	-	296	209
Iowa	1,061	-	3,780	2,141
Idaho	279	-	758	496
Illinois	1,135	-	4,044	2,291
Indiana	1,298	-	4,623	2,619
Kansas	70	-	315	71
Kentucky	553	-	1,594	999
Louisiana	3	-	18	5
Massachusetts	1	-	2	1
Maryland	930	-	3,114	1,559
Maine	0	-	0	0
Michigan	129	-	387	241
Minnesota	1,017	-	3,051	1,902
Missouri	1,218	-	4,338	2,458
Mississippi	232	-	1,276	381
Montana	101	-	274	179
North Carolina	617	-	1,779	1,115
North Dakota	83	-	377	85
Nebraska	118	-	531	120
New Hampshire	0	-	1	1
New Jersey	176	-	591	296
New Mexico	0	-	0	0
Nevada	4	-	11	7
New York	828	-	2,773	1,389
Ohio	211	-	750	425
Oklahoma	88	-	299	155
Oregon	98	-	304	158
Pennsylvania	761	-	2,550	1,277
Rhode Island	0	-	0	0
South Carolina	77	-	179	127
South Dakota	19	-	86	19
Tennessee	361	-	1,042	653
Texas	351	-	1,188	617
Utah	0	-	0	0
Virginia	602	-	1,736	1,088
Washington	1,288	-	4,006	2,087
Wisconsin	1,778	-	5,333	3,325
West Virginia	4	-	11	7
Wyoming	0	-	0	0
United States	18,287	-	64,005	31,913

[1] Benefits deemed most likely.

Table 3.18—Annual benefits of conservation tillage associated with reduced wind erosion on untreated HEL

State	Range			Best[1]
	1,000 dollars			
Arizona	0	-	0	0
California	0	-	0	0
Colorado	4,493	-	12,981	6,491
Idaho	1,994	-	5,760	2,880
Kansas	457	-	1,329	623
Montana	576	-	1,664	832
North Dakota	328	-	954	447
Nebraska	770	-	2,241	1,050
New Mexico	108	-	311	155
Nevada	112	-	324	162
Oklahoma	0	-	0	0
Oregon	82	-	246	100
South Dakota	0	-	0	0
Texas	0	-	0	0
Utah	17	-	48	24
Washington	473	-	1,420	579
Wyoming	207	-	599	299
United States	12,196	-	35,098	17,597

[1]Benefits deemed most likely.

Table 3.19— Benefits of conservation tillage in 1996 associated with reduced sheet and rill erosion

State	Soil erosion	Nominal soil erosion benefits		
		Range		Best[1]
	1,000 tons per year	*1,000 dollars*		
Alabama	865	1,012	- 2,344	1,661
Arkansas	399	595	- 3,267	975
Arizona	11	7	- 19	12
California	170	260	- 809	421
Colorado	166	105	- 284	186
Connecticut	21	88	- 294	147
Delaware	192	806	- 2,700	1,352
Florida	47	55	- 126	90
Georgia	338	395	- 916	649
Iowa	4,659	2,656	- 9,459	5,358
Idaho	402	253	- 687	450
Illinois	10,616	6,051	- 21,550	12,208
Indiana	6,553	3,735	- 13,303	7,536
Kansas	1,950	1,092	- 4,933	1,111
Kentucky	3,078	2,401	- 6,927	4,341
Louisiana	174	259	- 1,424	425
Massachusetts	0	0	- 1	0
Maryland	1,085	4,567	- 15,295	7,658
Maine	0	0	- 0	0
Michigan	1,404	2,808	- 8,423	5,250
Minnesota	2,881	5,762	- 17,286	10,775
Missouri	6,838	3,897	- 13,881	7,863
Mississippi	593	883	- 4,848	1,446
Montana	1,545	973	- 2,642	1,730
North Carolina	1,254	978	- 2,821	1,768
North Dakota	2,129	1,192	- 5,385	1,213
Nebraska	2,744	1,536	- 6,941	1,564
New Hampshire	0	0	- 0	0
New Jersey	154	646	- 2,165	1,084
New Mexico	0	0	- 0	0
Nevada	0	0	- 0	0
New York	141	592	- 1,983	993
Ohio	5,782	3,296	- 11,738	6,650
Oklahoma	898	1,033	- 3,495	1,815
Oregon	276	423	- 1,316	686
Pennsylvania	158	665	- 2,229	1,116
Rhode Island	0	2	- 5	3
South Carolina	195	228	- 529	375
South Dakota	1,646	922	- 4,165	938
Tennessee	3,359	2,620	- 7,557	4,736
Texas	998	1,148	- 3,882	2,016
Utah	0	0	- 0	0
Virginia	488	381	- 1,099	688
Vermont	1	3	- 10	5
Washington	898	1,373	- 4,272	2,226
Wisconsin	910	1,819	- 5,458	3,402
West Virginia	28	22	- 63	39
Wyoming	5	3	- 9	6
United States	66,049	57,544	- 196,539	102,968

[1] Benefits deemed most likely.

Table 3.20— Benefits of conservation tillage in 1996 associated with reduced wind erosion

State	Soil erosion	Nominal soil erosion benefits		
		Range		Best[1]
	1,000 tons per year	*1,000 dollars*		
Arizona	534	961	- 2,776	1,388
California	455	410	- 1,229	501
Colorado	2,969	2,969	- 7,720	3,860
Idaho	1,279	2,302	- 6,650	3,325
Kansas	1,218	1,340	- 3,897	1,827
Montana	6,790	6,790	- 17,653	8,827
North Dakota	7,115	3,557	- 11,384	4,980
Nebraska	456	502	- 1,460	684
New Mexico	1,347	2,425	- 7,006	3,503
Nevada	31	56	- 162	81
Oklahoma	0	0	- 0	0
Oregon	212	191	- 572	233
South Dakota	3,225	3,548	- 10,320	4,838
Texas	3,973	5,959	- 16,686	9,138
Utah	53	95	- 275	138
Washington	1,819	1,637	- 4,910	2,000
Wyoming	11	20	- 56	28
United States	31,486	32,760	- 92,755	45,349

[1] Benefits deemed most likely.

Table 3.21—Benefits of conservation compliance associated with reduced sheet and rill erosion

Crop residue cover	Planted Acres	Residue planned	Residue actual	Soil loss before[1]	Soil loss after[2]	Nominal soil erosion benefits		
						Range		Best[3]
Percent	*Million acres*	*Percent*		*T/a/yr*[4]		*Million dollars*		
0	22.9	0.0	3.5	15.2	5.8	71.0	- 206.4	148.4
< 15	6.2	9.4	31.6	9.9	5.0	10.0	- 29.0	20.9
15-29	18.0	21.0	39.7	11.6	5.3	37.5	- 108.9	78.3
30-39	21.5	31.1	45.8	14.7	5.5	65.2	- 189.5	136.2
40-59	17.2	44.8	53.5	19.3	7.1	69.2	- 201.3	144.7
> 59	5.3	71.5	73.2	20.3	6.4	24.2	- 70.4	50.6
Total	91.0	24.7	36.0	15.1	5.9	276.9	- 805.6	579.1

[1] Before the implementation of conservation compliance
[2] After all conservation management systems and technical practices were implemented
[3] Benefits deemed most likely
[4] T/a/yr denotes tons per acre per year

- A number of policy tools are used to reduce soil erosion from agricultural lands in the United States, including education and technical assistance, financial assistance, land retirement, and conservation-compliance requirements.

- Education and technical assistance by public and private sources can be effective in promoting the adoption of conservation tillage by farmers for whom that practice will be profitable.

- Financial incentives may be necessary to induce the voluntary adoption of conservation tillage by farmers for whom the practice would not be more profitable than conventional tillage but on whose land the use of conservation tillage would provide substantial offsite benefits.

Soil erosion associated with agricultural production practices can impose significant costs on both the public and private sectors. The adoption of conservation practices, such as conservation tillage, contour farming, filter strips, grassed waterways, terracing, polyacrylamide, and grasses and legumes in rotation, can reduce soil erosion and the transport of sediments and chemicals to off-farm water bodies. Several public policies can be used to affect farmers' choices of production practices and technologies: education and technical assistance, financial assistance, research and development, land retirement, and regulation and taxes. Each policy has implications about agricultural profits and the allocation of public funds.

Policies Designed to Affect the Adoption of Specific Production Practices

Education and Technical Assistance

If a preferred practice would be profitable for a farmer but the farmer is unaware of its benefits, education efforts can lead to voluntary use of the practice. Educational activities generally take the form of demonstration projects and information campaigns in print and electronic media, newsletters, and meetings. Demonstration projects provide more direct and detailed information about farming practices and production systems, and how these systems are advantageous to the producer (Bosch et al., 1995). Information assumes an especially significant role in the case of new or emerging technologies (Saha et al., 1994). When adoption of a practice would lead to an increase in long-term profits, but either new skills are needed or farming operations must be adapted for the practice to produce the highest net benefits, technical assistance can be provided to those who choose to adopt. Technical assistance is the direct, one-on-one contact provided by an assisting agency or private company for the purpose of providing a farmer with the planning and knowledge necessary to implement a particular practice on the individual farm. Requirements for successful implementation vary between individual farms because of resource conditions, operation structure, and owner/operator managerial skill. Testing a practice on part of the farm enhances its potential for adoption (U.S. Congress Office of Technology Assessment, 1990, and Nowak and O'Keefe, 1995). Technical assistance is often critical, especially for practices that require a greater level of management than the farmer currently uses (Dobbs et al., 1995). Both education and technical assistance can be provided by either public or private sources, and

both will induce adoption by farmers for whom the practice would be more profitable than the one they had been using.

Financial Assistance

Financial assistance can be offered to overcome either short- or long-term impediments or barriers to adoption. If the practice would be profitable once installed but involves initial investment or transition and adjustment expenses, a single cost-share payment can be used to encourage the switch to the preferred practice. Transition and adjustment costs include lost production, increased risk, or increased management costs due to learning how to use the new production practice efficiently. Financial and organizational characteristics of the whole operation also may be a hindrance to adoption (U.S. Congress Office of Technology Assessment, 1990, and Nowak, 1991). When the practice would not be more profitable to the farmer than the current practice but the environmental or other off-farm benefits are substantial, public funds could be allocated on an ongoing basis to defray the loss in profits to the farmer. Another form of financial incentive could be to grant a tax credit for investment in a particular practice. From a public perspective, the optimal financial assistance rates are those that induce the adoption of desired practices at the least cost. Efficient rates would have to be set individually since farm and farmer characteristics vary widely (Caswell and Shoemaker, 1993). Therefore, for ease of implementation, most large financial assistance programs specify a uniform subsidy rate across resource conditions.

Uniform rates, when used in assistance programs, invariably introduce production distortions. Because resource and production characteristics vary widely, different farms may need different sets of practices to achieve the same environmental goal. A production system that is appropriate for one farm may be inappropriate for another. The effectiveness of a conservation system in controlling erosion depends on several factors, including the frequency, timing, and/or severity of wind and precipitation; the exposure of land forms to weather; the ability of exposed soil to withstand erosive forces; the plant material available to shelter soils; and the propensity of production practices to reduce or extenuate erosive forces. An efficient financial assistance program would have a list of eligible management practices that included all alternatives appropriate for each farm. Cost-share and incentive payment policies are based on the fact that targeted farmers would not voluntarily adopt the preferred practice but public interest calls for the practices to be used more widely. Financial assistance is not a substitute for education and technical assistance—even with financial assistance, a farmer will not adopt an unfamiliar technology.

Research and Development (R&D)

Research and development policies can be used to enhance the benefits of a given production practice. The objective of the research would be either to improve the performance or to reduce the costs of the practice. Data gathering and analysis, as well as monitoring, contribute to R&D by providing information necessary to assess the determinants of adoption and the effectiveness of practices in achieving public goals. In addition, R&D funds could be allocated to ensure that the practice is adaptable for more circumstances. R&D is a long-term policy strategy with an uncertain probability of success, but it may also reap the greatest gains in encouraging the voluntary adoption of a preferred technology because it can increase the profitability of the practice for a wider range of potential adopters.

Land Retirement

The policy with the largest impact on farmers' choice of practices or technologies is land retirement. The underlying premise is that large public benefits can be gained by radically changing agricultural practices on particular parcels of land and that changes in individual

practices would not provide sufficient social benefits. For an individual to agree voluntarily to put the land in conserving uses, he or she would expect compensation in an amount at least as great as the lost profits from production. The payment mechanisms that can be used to implement land retirement strategies are lump sum payments or annual "rental fees." In the former, often referred to as easements, the farmer's right to engage in nonconserving uses is purchased by the public sector for a specific period. Payment to an individual to retire land would result in a voluntary change in practices.

Regulation, Taxes, and Tax Incentives

If voluntary measures prove insufficient to produce the changes in practices necessary to achieve public goals, regulation is a policy that can be used. The use of certain practices could be prohibited, taxed, or made a basis for withholding other benefits. Preferred practices could be required or tax incentives offered to promote their use, thereby offsetting some of the cost of new conservation tillage equipment. Point sources of pollution have been subject to command-and-control policies for many years. There are recognized inefficiencies associated with technology-based regulations because the least-cost technology combination to meet an environmental goal for an individual may not be permitted.[45] It has been assumed that such a loss in efficiency is made up for by ease of implementation.

Policies to control soil erosion on agricultural lands have been administered mainly by the U.S. Department of Agriculture. The following section describes the policies used by USDA to promote soil conservation.

U.S. Department of Agriculture Soil Conservation Policies

The conservation and related water quality programs administered by the U.S. Department of Agriculture were designed chiefly to induce the voluntary adoption of conservation practices. To encourage adoption, USDA has used a number of policy tools, including on-farm technical assistance and extension education, cost-sharing assistance for installing practices preferred, rental and easement payments to take land out of production and place it in conservation uses, R&D for evaluating and improving conservation practices and programs, and compliance provisions that require the implementation of specified conservation practices or the avoidance of certain land use changes if a farmer wants to be eligible for Federal agricultural program payments. Regulatory and tax policies have not been part of the traditional voluntary approach of U.S. conservation programs. USDA policy has been to decrease government involvement in farm operations (Reichelderfer, 1990).

USDA conservation programs are closely tied to State and local programs. Federal and State agencies cooperate with a system of special-purpose, local (county) conservation districts authorized by State law to provide education and technical assistance to farmers and with county Agricultural Stabilization and Conservation (ASC) committees to handle cost-sharing (Libby, 1982).[46] The system assures that financial support and technical assistance are focused

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[45] Economic theory shows that the efficient solution (i.e., least cost for society to achieve a particular level of environmental quality) is when the marginal cost of pollution reduction is the same for all producers (Kneese and Bower, 1968). Each individual could have different combinations of practices and technologies. To implement such a policy, however, would have an extremely high cost for an industry as large and diverse as agriculture (Heffernan, 1984).

[46] The supervision of these committees was transferred to the Farm Service Agency with the passage of the Federal Agricultural Improvement and Reform Act of 1996. The committees were renamed to State Technical Committees.

on the set of problems relevant to the geographic region and the national interest. The adoption of an alternative production practice generally does not occur as a consequence of any one specific assistance program (Missouri MSEA, 1995). The USDA has a memorandum of understanding with each conservation district to assist in carrying out a long-term program.[47] Conservation districts have proven to be practical organizations through which local farmers and the Federal Government can join forces to carry out needed soil conservation practices (Rasmussen, 1982). The demand for information has changed over time. Not long ago, an extension agent was the primary source of information on new technologies (van Es, 1984, and Heffernan, 1984). Now, however, farmers are relying on many additional sources of information, including newspapers, magazines, agrichemical dealers, crop consultants, and the Internet.

The U.S. Department of Agriculture Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service, provides technical assistance to farmers and other land users, including local, State, and Federal agencies that manage publicly owned land. NRCS helps district supervisors and others to draw up and implement conservation plans.

Providing Federal cost-sharing assistance to farmers for voluntary installation of approved conservation practices is the responsibility of State and county ASC committees. Through the Agricultural Conservation Program (ACP), funds were allocated among the States through the State ASC committees on the basis of soil and water conservation needs. ACP practices eligible for cost sharing were established by a national review group representing all USDA agencies with conservation program responsibilities, the Environmental Protection Agency, and the Office of Management and Budget. The practices were designed to help prevent soil erosion and water pollution from animal wastes or other nonpoint sources, to protect the productive capacity of farmland, to conserve water, to preserve and develop wildlife habitat, and to conserve energy (Holmes, 1987).[48]

The Secretary of Agriculture can also target critical resource problem areas for financial and technical assistance based on the severity of the problem and the likelihood of achieving improvement. Highly erodible and/or environmentally sensitive cropland has recently been targeted because the greatest net social benefits were expected to be associated with a reduction in soil erosion on these lands. Targeting, however, will not guarantee that the net benefits (public and private) of any conservation practice will be positive, because net benefits are a function of site-specific factors.

The policy to take land out of production and place it into conservation uses was first used in the Soil Bank Program of the 1950's, and has been significantly increased in the current Conservation Reserve Program (CRP). The Conservation Reserve Program allows for the USDA to enter into 10-15 year agreements with owners and operators to remove highly erodible and other environmentally sensitive cropland from production. Along with conservation, the CRP originally had a second objective of reducing surplus crop production

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[47] Many conservation programs to be implemented at the State and local levels require States to submit plans or project proposals and funding needs for Federal approval before actual funds are transferred. For multiyear projects, annual plans of work and documentation of progress are required to receive continued funding. A summary of State programs for erosion control is provided in Magleby et al. (1995).

[48] Authority for ACP was terminated on April 4, 1996, when its functions were subsumed by the Environmental Quality Incentives Program (EQIP).

(Osborn, 1996). The more recent emphasis on CRP, however, has been to provide environmental benefits rather than to control the supply of commodities.

Most of the highly erodible land (HEL) contracted into the CRP had suffered much erosion, organic matter loss, and structural deterioration while it was in cultivated crop production.[49] When lands are returned to grass, their structure and organic matter improve and tend to approach the structure and organic matter content of the original grassland soils (Gebhart et al., 1994). The degree of soil improvement from 10 years of grass is a function of site-specific factors. As a general rule, the greater the amount of soil structure deterioration from past cultural practices, the more likely that grass management will improve the soil's characteristics. Rasiah and Kay (1994) found that if soils had higher levels of organic matter and other stabilizing materials at the time of grass introduction, the time required for soil structure regeneration was reduced. Soils in the CRP typically fit into the category of degraded soils whose organic matter is lower than that of surrounding soils, because they were primarily allowed into the program based on their highly erodible classification (Lindstrom et al., 1992, and Barker et al., 1996).

CRP contracts are beginning to expire, so farmers have the option to return the land to crop production. For land that would be returned to production, the improvements in soil quality and erosion reduction gained during the CRP contracts will be rapidly lost if conventional tillage is used. A concern is whether it will be possible to maintain the benefits derived from 10 years of grass. There are several options for post-CRP land.

1. Keep HEL land in the CRP. This would allow the soil in the program to continue to improve and maintain the erosion benefits.

2. Subsidize a rotation that involves 4 years in grass production followed by 4 years in grain production.

3. Lower CRP payments to keep the land in grass but allow grazing or haying on the land. This proposal has met with considerable opposition by farmers who have land already in hay production and who object to subsidized hay production that would compete with their commodity (Schumacher et al., 1995).

The focus of current conservation research has been on the development of environmentally acceptable and sustainable production practices to gain a better understanding of how different soils respond to tillage, what amount of tillage is necessary for optimum crop growth, and what combination of mechanical, chemical, and biological practices are needed to create environmentally sustainable crop production. Many conservation practices have been evaluated by the land-grant university experiment stations discussed in chapter 3 (Moldenhauer et al., 1994). USDA has funded several major surveys to provide data to assess the extent and determinants of adoption for particular production practices across a wide range of crops and regions.[50] A more in-depth discussion of conservation-related R&D can be found in Karlen (1990).

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[49] Highly erodible land is cropland that has an erodibility index greater than or equal to eight. The technical definition of the erodibility index as well as other relevant terms is presented in the appendix to chapter 3.

[50] Analyses conducted using these data are described in chapter 3 of this report.

The major shift in U.S. conservation policy came in the Food Security Act of 1985 in the form of conservation compliance (Heimlich, 1991). This provision provided farmers with a basic economic incentive to adopt conservation tillage practices or another acceptable plan because agricultural program payments were linked to the adoption of an acceptable conservation system on highly erodible land. While meeting the conservation provisions remains voluntary, a farmer who wants to receive certain agricultural program payments and whose cropland is designated as HEL has no choice but to implement an acceptable conservation plan (Crosswhite and Sandretto, 1991). The conservation-compliance provision was innovative because it linked farm program payments (private benefits) to conservation performance (social benefits).[51] In 1982, cultivated HEL accounted for almost 60 percent of the total erosion on U.S. cropland in terms of tons per acre per year while it accounted for only 40 percent of total planted acreage (Magleby et al., 1995). Requirements for conservation compliance were applied to HEL previously cultivated in any year between 1981 and 1985. Conservation compliance required farmers producing crops on HEL to implement and maintain an approved soil conservation system by 1995.

Acceptable conservation plans specify economically viable conservation systems designed to reduce soil erosion. Conservation systems are composed of one or more conservation practices. The 1995 status review of approved conservation systems by the Natural Resources Conservation Service provides the first assessment of fully implemented conservation systems under conservation compliance (USDA NRCS, 1996). Although the 1995 status review found over 4,000 different conservation systems (combinations or practices) applied throughout the United States, four conservation systems involving conservation cropping sequences, crop residue use, or a combination of these practices with conservation tillage accounted for approximately half of planted HEL acreage (table 4.1).

Regional differences in the adoption of specific conservation systems can be illustrated by a comparison of the conservation plans from Iowa, North Carolina, North Dakota, and Oklahoma. In the relatively homogeneous Northern Plains, there are few economically viable alternatives to a wheat/fallow rotation. Consequently, in North Dakota, a conservation crop sequence/crop residue management system was part of nearly all conservation systems used on planted HEL in 1995 (table 4.2). Analogously, in the Southern Plains, wheat is the predominant crop, with few economically viable alternatives. In Oklahoma, most approved conservation systems consist of a single technical practice: crop residue management. Both the number of viable conservation systems and the number of systems required to control erosion effectively are greater in areas with relatively greater climatic and geographic variability. Iowa produced predominantly corn and soybeans, and has a higher average rainfall and more varied topography than North Dakota and Oklahoma. As a result, a larger number of conservation systems are used in Iowa, most frequently conservation cropping sequences and conservation tillage. North Carolina has a variable topography with diverse soils and precipitation patterns and produces a large number of different agricultural commodities including wheat, corn, soybeans, cotton, sorghum, and tobacco. Consequently, the conservation systems used in North Carolina are even more varied than they are in Iowa.

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[51] Technically, the Food Security Act of 1985 is not the first instance of recognizing the off-site damages of soil erosion and hence the need to target conservation programs. The Soil Conservation Service in 1981 moved to target an increasing proportion of soil erosion programs to areas of high erosion rates in order to reduce substantial off-site damages, and the Agricultural Stabilization and Conservation Service began targeting its Agricultural Conservation Program (ACP) in 1982. The success of these efforts is assessed in Nielson (1985). Targeting became a general policy instrument, however, with the passage of the Food Security Act of 1985.

The most recent manifestation of agricultural program policy is the Federal Agriculture Improvement and Reform (FAIR) Act of 1996. It modifies the conservation compliance provisions of the Food Security Act of 1985 to provide farmers with greater flexibility in developing and implementing conservation plans, in self-certifying compliance, and in obtaining variances for problems affecting application of conservation plans. Producers who violate conservation plans, or fail to use a conservation system, on highly erodible land risk loss of eligibility for many payments, including production flexibility contract payments. An important aspect of this Act is that in self-certifying compliance, there is no requirement that a status review be conducted for producers who self-certify (Nelson and Schertz, 1996). The FAIR Act also does not differentiate between previously cultivated and uncultivated land, thereby eliminating the sodbuster program.[52] Newly cropped, highly erodible land may use conservation systems other than the systems previously required under the sodbuster program.

Additionally, the FAIR Act established a new program, the Environmental Quality Incentive Program (EQIP), that incorporated the functions of ACP and some other environmental programs, and is designed to encourage farmers to adopt production practices that reduce environmental and resource problems. The acceptable plans will improve soil, water, and related natural resources including grazing lands, wetlands, and wildlife habitat. EQIP must be carried out to maximize environmental benefits provided per dollar expended. During 1996-2002, the Secretary of Agriculture will provide technical assistance, education, and cost-sharing to producers who enter into 5- to 10-year contracts specifying EQIP conservation programs. Based on the historical experience of the ACP, very little of the EQIP funds are likely to be targeted at farmers using conservation tillage.[53]

Policy Impacts on the Adoption of Conservation Tillage

The adoption of any agricultural technology is a function of many things. As described above, the choice of practice is influenced by farm and farmer characteristics, attributes of the technology, economic conditions, and policies. To sway farmers to adopt conservation tillage, some factors are easier to influence than others. For example, ownership characteristics can also influence the adoption of conservation tillage. Owner-operators are more likely to have greater flexibility to adopt conservation tillage than nonowner-operators who must often get approval from the owner before making production practice changes. Conservation tillage may tax the managerial skill of the operator (Nowak, 1991). Farmers typically make production decisions within a short time frame, a fact that may discourage investment in measures that increase returns only over the long run, as may be the case with conservation tillage (U.S. Congress Office of Technology Assessment, 1990, and Tweeten, 1995). Risk-averse producers do not look favorably upon practices that are perceived as being too risky and, in many situations, conservation tillage is more risky than conventional tillage because of the timing and managerial aspects and greater variability in yields. Also, access to capital may depend on risk. There is a relatively greater chance that something might go wrong with conservation tillage, causing net returns to fall (Fox et al., 1991).

Most conservation policies attempt to influence the use of conservation tillage through demonstrating or ensuring that net benefits of adoption are positive. The policies that have

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[52] Note that the sodbuster program was applicable to HEL uncultivated between 1981 and 1985.

[53] In 1995, only 2.36 percent of ACP expenditures of $142.4 million went for conservation tillage practices (Farm Service Agency, 1996). Of the 84,258 farms receiving ACP payments in 1995, only 3,866 (4.6 percent) implemented a conservation tillage practice for which they were paid.

had the greatest impact to date have been those focusing on education and technical assistance. The management complexities associated with conservation tillage relative to conventional tillage are considerable. Farming with conservation tillage requires a different approach to soil preparation, fertilizer application, and weed and insect control. Moreover, conservation tillage systems must be designed according to the unique conditions of the region and the specific needs of the individual farmer. Consequently, it is not feasible to design a conservation tillage system that can be applied at all locations across the United States or even within a single region. A successful conservation tillage system must be developed from a whole-system point of view. Simply stopping tillage with no other changes in the cropping system increases the potential for problems and failure (Schumacher et al., 1995).

Farmers' reluctance to adopt conservation tillage, even under favorable economic conditions where the net private benefits of adoption would be positive, can be due to a lack of information, a high opportunity cost associated with obtaining information, complexity of the production system, a short planning horizon, inadequate management skills, and a limited, inaccessible, or unavailable support system (Nowack, 1992). Westra and Olson (1997) conducted a survey of farmers in Scott and Le Sueur Counties in Minnesota. They found that several noneconomic factors impact the decision to use conservation tillage, including whether the farmer perceived he or she has the requisite management skill for conservation tillage use and whether conservation tillage fits in with the farmer's production goals and physical setting of the farm. One surprising result from the survey was that 47 percent of the respondents indicated that they knew nothing about conservation tillage. The surveyed counties, however, have little acreage designated as highly erodible.

Education and technical assistance programs funded by the government can be effective in increasing the use of conservation tillage (Logan, 1990). Dickey and Shelton (1987), for example, discuss the education programs in eastern Nebraska that targeted specific areas that were susceptible to relatively high soil erosion rates. The program succeeded in increasing the use of conservation tillage by 20 percent and in reducing soil erosion by 20 percent in the target areas.

Education and technical assistance to mitigate the impediments to use of conservation tillage associated with real or perceived management inadequacies can come in a variety of forms, not just through extension education and county agents who work for the government. A large amount of information is available through land-grant universities, agrichemical dealers, and independent crop consultants. For example, the Washington State University Agriculture Extension Service has prepared the *Pacific Northwest Conservation Tillage Handbook*, which addresses virtually all management issues associated with the adoption of conservation tillage in the Pacific Northwest (WSU Agriculture Extension Service, 1997). The Agricultural and Biosystems Engineering Department at Iowa State University has produced the publication *Conservation Tillage Systems and Management*, which addresses management problems associated with conservation tillage in the Midwest (Midwest Plan Service, 1992). Private groups also provide management information. The Conservation Technology Information Center prepares publications like *Conservation Tillage: A Checklist for U.S. Farmers* (Conservation Technology Information Center, 1997), which address the management of weeds, insects, diseases, and nutrients for farmers using conservation tillage. Thus, there are quite a few publications available in hard copy or through the Internet that address management issues associated with conservation tillage.

Agricultural input supply dealers and crop consultants are also good sources of information on the management complexities associated with conservation tillage and how to deal with them.

Fertilizer and pesticide dealers and crop consultants have consistent access to farmers and consequently have the potential for exercising great influence on the tillage system used (Center for Agricultural Business, 1995). Until recently, there was little information on the influence of dealers and consultants in tillage decisions. Recent survey instruments include questions about whether decisions are influenced by these sources, but there still are no objective studies that quantify the impact of dealers and crop consultants in assisting farmers on the use of conservation tillage with various other management problems (Wolf, 1995). Education and technical assistance efforts will succeed in inducing adoption of conservation tillage only by those farmers who can be shown that they will reap net benefits in the long run. For farmers with production or resource characteristics for which conservation tillage is not profitable, education and technical assistance will not be a sufficient inducement to adopt.

Another impetus to increasing the use of conservation tillage would be the return of Conservation Reserve Program acreage to crop production. The adoption of conservation tillage appears to provide the greatest potential for achieving positive net private benefits while retaining most of the soil quality improvement achieved during the CRP while coincidentally mitigating soil erosion relative to conventional tillage (Veseth et al., 1997). The precise strategy to follow, however, depends on weed problems, water availability, seasonal workload, the economics of crop options, and so forth—in other words, site-specific factors.

Conservation tillage has proven to be an important component of conservation plans developed under conservation compliance provisions (tables 4.1 and 4.2). Adherence to a conservation plan often entails some costs for most farmers. Often, the plan requires the purchase of new equipment to implement a conservation tillage system and human capital expenses to learn new production practices. Farmers who consider adopting conservation tillage in the future must consider these sorts of extra in making their production decisions. Costs and benefits of the adoption of conservation tillage to society as a whole are much more difficult to measure.[54] While higher production costs and reduced output would ostensibly lead to higher consumer costs for food and fiber, there is scant evidence that this has occurred *de facto*. If consumer costs have risen, the rise has been relatively modest (Young et al., 1991).

A farmer whose cropland is highly erodible and who adopts conservation tillage as part of a conservation plan will benefit by controlling the rate of soil erosion, thereby maintaining the long-term productivity of the soil. The significance of this benefit depends on a number of elements, including current topsoil depth, erosion rates, and the rate at which the farmer discounts benefits in future years. Unlike many other conservation practices, conservation tillage has an added benefit—it can lead to an increase in soil organic matter, an increase in soil moisture, reduced soil compaction, etc., all of which have the potential to enhance soil quality, leading to relatively greater yields in the long run and an increase in the value of a farmer's primary asset, the land.

Conclusion

Soil conservation programs in the United States have traditionally employed four major tools to encourage the adoption of preferred practices and technologies: education and technical assistance, financial assistance, crop acreage diversion programs, and, more recently, conservation compliance.

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[54] This is not a problem associated only with conservation tillage. Rather, it is characteristic of most agricultural programs (Council of Economic Advisors, 1997).

Conservation tillage is one of the practices that can be used to reduce soil erosion and maintain productivity of agricultural land. Education and technical assistance are effective mechanisms for increasing the use of conservation tillage by farmers for whom the technology will be profitable. Given the management complexities associated with the use of conservation tillage, the availability of education and technical assistance is critical. Education and technical assistance, however, do not have to come exclusively from the public sector. The private sector, through commodity groups, input suppliers, and crop consultants, can have a strong influence on decisions made by farmers.

For farmers who would not gain from the adoption of conservation tillage, financial incentives would be necessary to induce the voluntary change of practices. Such a policy is in the public interest if the offsite benefits of adoption outweigh the costs of the financial assistance program.

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Table 4.1—Conservation management systems and technical practices being applied on cultivated HEL subject to compliance (excluding CRP), 1995

Item	Acreage	Percent of cultivated HEL[1]
Management systems[2]		
Conservation cropping sequence/crop residue use	27,443,973	30.2
Conservation cropping sequence/conservation tillage	9,081,148	10.0
Conservation cropping sequence only	6,249,209	6.9
Crop residue use only	4,041,388	4.4
Conservation cropping sequence/conservation tillage/ grassed waterways	2,027,771	2.2
Conservation cropping sequence/conservation tillage/ grassed waterways/terrace	1,958,476	2.2
Conservation cropping sequence/contour farming/ crop residue use/terrace	1,896,080	2.1
Conservation cropping sequence/crop residue use/ wind strip cropping	1,768,605	1.9
Conservation cropping sequence/contour farming/ crop residue use/grassed waterways/terrace	1,665,697	1.8
Conservation cropping sequence/conservation tillage/ crop residue use	1,602,604	1.8
Total	57,734,951	63.5
Technical practices[3]		
Conservation cropping sequence	75,632,767	83.1
Crop residue use[4]	48,294,496	53.1
Conservation tillage[4]	28,477,584	31.3
Contour farming	18,046,999	19.8
Terrace	12,868,684	14.1
Grassed waterway	10,842,932	11.9
Field border	4,442,198	4.9
Wind strip cropping	3,508,340	3.9
Cover and green manure	3,169,983	3.5
Surface roughing	3,018,871	3.3
Grasses and legumes in rotation	2,424,281	2.7
Strip cropping-contour	1,699,477	1.9
Critical area planting	1,545,287	1.7
Pasture and hay land management	1,126,426	1.2

[1] Based on 91 million acres of cultivated HEL subject to compliance.
[2] 10 most frequently used systems.
[3] Because many conservation systems include multiple technical practices, percentages will sum to more than 100.
[4] Conservation tillage and crop residue management are frequently combined and reported as a single practice, conservation tillage.

Source: USDA, Economic Research Service (1997)

Table 4.2—Technical practices included in conservation plans in Iowa, North Carolina, North Dakota, and Oklahoma, 1995

Technical practice	Iowa	North Carolina	North Dakota	Oklahoma
	Percent of conservation plans[1]			
Conservation crop rotation	87.1	82.0	99.0	9.9
Conservation tillage	79.2	30.6	0.4	3.5
Residue management	0.7	50.5	98.4	92.3
Contour farming	44.4	24.3	*	5.4
Strip cropping - field border	32.3	15.0	*	*
Strip cropping - contour	2.3	*	*	*
Strip cropping - field	*	5.0	*	*
Strip cropping - wind	*	*	0.6	0.3
Grassed waterway - retired[2]	24.9	21.9	0.7	8.2
Grasses and legumes in rotation	1.0	7.2	*	*
Cover and green manure crop	*	5.1	1.5	0.3
Conservation cover - retired[2]	*	13.6	3.0	0.5
Critical area planting - retired[2]	0.8	4.3	0.1	0.6
Terrace	13.4	1.2	*	0.2
Pasture and hay land management	13.7	5.9	0.2	22.5
Pasture and hay land planting	1.3	6.3	0.4	0.3

* indicates less than 0.1 percent.

[1] Because many conservation systems include multiple practices, percentages will sum to more than 100.
[2] Retired indicates land taken out of production.

Source: USDA, Economic Research Service (1997)

V. Summary

Soil erosion has both onfarm and off-farm impacts. Reduction of soil depth can impair the land's productivity, and the transport of sediments and adhering chemicals can degrade streams, lakes, and estuaries. Many individual conservation practices and combinations of practices can be used to reduce soil erosion. The system used will depend on farm and farmer characteristics, attributes of the practices, economic conditions, government policies, and the value of the environmental resources affected by erosion. To be functional, the system must be manageable and economically viable (Natural Resources Conservation Service, 1997). Conservation tillage is only one of the conservation practices that farmers may consider. On highly erodible land as well as nonhighly erodible land, conservation tillage can offer substantial benefits to farmers by sustaining productivity, and to the public by reducing sediment and chemical loadings in water bodies. Farmers also gain from improved soil qualities such as increased organic matter and water-holding capacity, and the public will benefit from improvements in wildlife habitat and carbon sequestration.

Soil conservation policies have existed in the United States for more than 60 years. Initially, these policies focused on the onfarm benefits of keeping soil on the land and increasing net farm income. Beginning in the 1980's, however, policy goals increasingly included reductions in off-site impacts of erosion. Conservation tillage was one of the practices that was included in the suite of best management practices (BMPs) recommended within conservation programs. The Food Security Act of 1985 was the first major legislation explicitly to tie eligibility to receive agricultural program payments to conservation performance. The use of conservation tillage on highly erodible land increased significantly as the conservation compliance provisions of the 1985 Food Security Act took effect. The Federal Agriculture Improvement and Reform Act (FAIR) of 1996 modified the conservation compliance provisions by providing farmers with greater flexibility in developing and implementing conservation plans. Noncompliance on highly erodible land can result in loss of eligibility for many payments including production flexibility contract payments.

The current definition of conservation tillage was not developed until 1984. Therefore, it is difficult to determine long-term trends in use and the impact of specific factors on these trends. The emphasis now is on leaving crop residue on the soil surface after planting. Using a broad definition, it was shown that the use of conservation tillage increased from 2 percent of planted acreage in 1968 to nearly 36 percent of planted acreage in 1996.

Use of conservation tillage varies significantly by crop and by geographic region. The practice is used mostly on corn, soybeans, and small grains. Of the major field crops, cotton has the lowest proportion of acreage under conservation tillage. Several important crops (peanuts, potatoes, sugar beets, tobacco, and vegetables) require production practices incompatible with conservation tillage. Therefore, policies to encourage adoption on acreage growing these crops will be less successful. Regional differences in adoption rates for conservation tillage are also substantial. For example, Kentucky has 73 percent of its cropland acreage in conservation tillage versus less than 10 percent for most of New England.

The private benefits to farmers from use of conservation tillage depend on many site-specific factors. A survey of yield and cost differences between conservation tillage and conventional tillage systems shows inconclusive results. In some circumstances conventional tillage is more profitable, and in other situations conservation tillage is more profitable. The larger the

difference a farmer perceives in net benefits between conservation and conventional tillage systems, the higher the probability that he or she will choose the more profitable option. The effects of adoption on some input uses also is not clear. Although herbicide use in conservation tillage seems to increase in the short run, agronomists hypothesize that herbicide use will decrease in the long run. Recent surveys have shown that most farmers have been using conservation tillage for a relatively short time, however, so there is little experience from which to test the hypothesis.

The public benefits to be gained by use of conservation tillage also depend on site-specific factors. The gains from reducing sediment and chemical transport from highly erodible land can be significant, but off-site benefits from conservation tillage on non-highly erodible land may be relatively small.

Use of conservation tillage on an additional 48 million acres of HEL and 166 million acres of nonhighly erodible cropland (acres not currently using conservation tillage but growing crops for which high rates of conservation tillage adoption already exist) would yield a total reduction in erosion of 326 million tons per year.[55] Additionally, the benefits of converting the remaining 22.4 million acres of HEL on which no conservation system is currently used, to conservation tillage are relatively modest: approximately $50 million. Improvements in wildlife habitat and possible carbon sequestration would yield additional, but unquantifiable, benefits. The sum of all these benefits can be changed substantially by the total complement of production practices, not just those directly related to tillage activities.

Public education and technical assistance policies to promote the use of conservation tillage have been very effective. University and private sources of information assistance also influence farmers' technology choices when conservation tillage practices are profitable. When the adoption of conservation will provide significant public benefits but would not be profitable for the farmer, financial incentives may be necessary to elicit a voluntary change in farmer practices.

References

U.S. Department of Agriculture, Natural Resources Conservation Service, *A Geography of Hope*, 1997.

[55] See chapter 3 of this report for details of the study.

Appendix—Technical Definitions

The **Universal Soil Loss Equation**[56] for calculating sheet and rill erosion is

$$A = R * K * f(L,S) * C * P$$

where:

A is the computed soil loss per unit area, expressed in the units selected for K and for the periods selected for R. In practice, these are usually so selected that they compute A in tons per acre per year;

R, the rainfall and runoff factor, is the number of the rainfall erodibility index units plus a factor for runoff from snow melt or applied water where such runoff is significant;

K, the soil erodibility factor is the soil loss rate per erodibility index unit for a specified soil as measured on a unit plot, which is defined as a 72.6-ft length of uniform 9-percent slope continuously in clean-tilled fallow;

L, the slope length factor, is the ratio of soil loss from the field slope to that from a 72.6-ft length of uniform 9-percent slope continuously in clean-tilled fallow;

S, the slope steepness factor, is the ratio of soil loss from the field slope gradient to that from a 72.6-ft length of uniform 9-percent slope continuously in clean-tilled fallow;

C, the cover and management factor, is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous cover; and

P, the support practice factor, is the ratio of soil loss with a supporting practice like contouring, strip cropping, or terracing to that with straight-row farming up and down the slope.

Note that f(L,S) indicates a nonlinear relationship between L and S.

The **Wind Erosion Equation**[57] for calculating wind erosion is of the form

$$E = g(I, K, C, L, V)$$

where:

E, the potential average annual soil in tons per acre per year, is the erosion that would occur from a field that is level, smooth, wide, bare, unsheltered, isolated, and having a climatic factor of 100 percent;

I is the soil erodibility factor;

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[56] From Wischmeier and Smith (1978).

[57] From Skidmore and Woodruff (1980).

K, the roughness factor, reflects the presence of ridges which, if at right angles to the wind, reduces wind erosion by reducing surface velocity and trapping particles;

C, the climatic factor, accounts for the influence of wind velocity and surface soil moisture;

L is the unsheltered travel distance along the prevailing wind erosion direction for the field or area to be evaluated; and

V is the vegetation cover.

The functional notation g(*) indicates that the relationship is nonlinear.

The **Soil Loss Tolerance Level** (T) is the maximum rate of annual soil erosion that may occur and still permit a high level of crop productivity to be obtained economically and indefinitely. Most values for cropland in the United States are between 3 and 5 tons per acre per year.

The **Erodibility Index** is a number showing how many times the inherent erosion potential is of the soil loss tolerance (T) level. For water (sheet and rill) erosion, the number is calculated as

$$EI = R * K * L * S / T$$

where:

R, the rainfall and runoff factor, is the number of the rainfall erodibility index units plus a factor for runoff from snow melt or applied water where such runoff is significant;

K, the soil erodibility factor is the soil loss rate per erodibility index unit for a specified soil as measured on a unit plot, which is defined as a 72.6-ft length of uniform 9-percent slope continuously in clean-tilled fallow;

L, the slope length factor, is the ratio of soil loss from the field slope to that from a 72.6-ft length of uniform 9-percent slope continuously in clean-tilled fallow; and

S, the slope steepness factor, is the ratio of soil loss from the field slope gradient to that from a 72.6-ft length of uniform 9-percent slope continuously in clean-tilled fallow.

For wind erosion, EI is calculated as

$$EI = C * I / T$$

where:

I is the soil erodibility factor; and

C, the climatic factor, accounts for the influence of wind velocity and surface soil moisture.

For soils experiencing both water and wind erosion, the Erodibility Index is the greater of the EI for wind or EI for water.